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Section 1 - The following methods of protecting cooling systems against the detrimental influence of impurities contained in cooling water are discussed, with emphasis on Polish experience.

- removal of mechanical impurities contained in water drawn for cooling
- removal of mechanical and chemical sediments formed on condenser tubes
- protection of cooling systems against the formation of mechanical and chemical sediment or scale and biological fouling

Current techniques are evaluated and several proposals are presented. It is apparent that most technical approaches emphasize power production needs, while technical solutions which take into account both power engineering and the interests of the environment, such as fish protection, are less common.

Section 2 - Effects of power plant cooling systems on surface water quality are discussed based on investigations done for this project and on prior (see attached sheet)

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ENVIRONMENTAL EVALUATION OF EUROPEAN POWERPLANT COOLING SYSTEMS
A POLISH RESEARCH PROJECT

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FOREWARD

This report presents the results of a cooperative study by the Institute of Meteorology and Water Management of Warsaw, Poland. Funds were provided by the U.S. EPA under the Special Foreign Currency Program, P.L. 480, and by Poland under auspicies of the Maria Skladowska-Curie Fund. The report was submitted in three sections in accord with Project JB-5-537-4. The three sections and their authors are noted below:

Part 1. Equipment for Water Treatment and Condenser Cleaning in Once-Through Cooling Systems - M. Gadkowski

Part 2. Impact of Open and Closed Cooling Systems on Surface Water Quality - E. Czarnecka, M. Gadkowski and H. Spoz-Dragan

Part 3. Make-up Water Demand and Water Loss in Closed Cycle Cooling Systems - M. Gadkowski and H. Spoz-Dragan

ABSTRACT

Section 1 - The following methods of protecting cooling systems against the detrimental influence of impurities contained in cooling water are discussed, with emphasis on Polish experience.

- removal of mechanical impurities contained in water drawn for cooling
- removal of mechanical and chemical sediments formed on condenser tubes
- protection of cooling systems against the formation of mechanical and chemical sediment or scale and biological fouling

Current techniques are evaluated and several proposals are presented. It is apparent that most technical approaches emphasize power production needs, while technical solutions which take into account both power engineering and the interests of the environment, such as fish protection, are less common.

Section 2 - Effects of power plant cooling systems on surface water quality are discussed based on investigations done for this project and on prior Polish investigations. For open cycle cooling systems, no significant differences between influent and effluent concentrations of metals were determined. For closed cycle cooling systems, higher concentrations of metals in the effluent were found than predicted. The possible contribution of washout of air pollutants in the cooling tower is discussed.

Section 3 - Studies were conducted regarding the relation between evaporative water loss and makeup water demand at a number of Polish power plants with closed cycle cooling systems. Comparisons are made with similar results for other European power stations. Recommendations for reduction of water supply requirements at the Polish plants are given.

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1. EQUIPMENT FOR WATER TREATMENT AND CONDENSER CLEANING IN ONCE-THROUGH COOLING SYSTEMS

1.1 Cooling System Impurities

Impurities found in once-through cooling systems can be categorized as mechanical, biological or chemical. Some Polish and European experience with the three types of impurities is described below.

1.11 Mechanical Impurities

Mechanical impurities may consist of parts of trees and plants floating in the water, tangles or single threads of algae and water fungi and sediments. These impurities may cause the clogging of intakes and other devices supplying water to the power plant. The collection and discharge of impurities retained on the intakes may sometimes create a serious problem. For example, in the Skawina (Poland) Steam Power Plant once-through cooling system several tons of algae and water fungi growing in the long inlet channels are collected daily on coarse grids in some periods of the year.

The clogging of the grills, screens and condensers by fry or by adult specimens of small fish may cause serious difficulties in the operation of the water intake. Cases of clogging of fine grills by fry swarms were noted on the water intake for the Siekierki Steam Power Plant in Warsaw during the first two years of operation of the plant. In this period, the catch sometimes amounted to several tons of fry daily. Also, at the Elblag Steam Power Plant (Elblag, Poland), cases of clogging of condensers by adult specimens of stickleback (Gasterostens Aculcatus Linne) were noted.

If the water contains large amounts of mineral suspensions, particularly of clay and Kaolin, these impurities may precipitate in the tubes of condensers.

1.12 Biological Impurities

Biological impurities may include colonies of various water organisms, which can foul the intake surfaces, or bacteria and small water organisms that may grow in the condenser tubes. The growth of water organisms in the condensers hinders the water flow through the condensers, impairs heat exchange and favors the development of biological corrosion. Biological corrosion occurs as a result of emissions by lichen and bacteria of substances resulting from bio-chemical decomposition.

In Poland, these circumstances have been noted for several years in the Stalowa Wola Steam Power Plant, which draws water from the relatively clean San River. During the winter (December and January), fouling of the condenser tubes by large fibrous floccules composed mainly from Mucor sp. (Phycomycetes) and Fusarium Aquaeductum (Myco-mycetes) fungi have been observed quite often; moreover, Sphaerotilus natans, a filamentous bacteria, have also been seen. The probable cause of the fouling was the waste discharged into the river by a sugar factory situated 70 km upstream of the water intake. The fouling was controlled by heating empty condensers to a temperature of 70° C. At this temperature, the fouling organisms were killed and then washed away by the cooling water. Due to this control technique, this fouling problem no longer occurs.

Biological contamination and the risk of fouling of surfaces is particularly important for sea water intakes. This problem is discussed more fully later in this report.

1.1.3 Chemical Impurities

Chemical impurities in cooling water may result in the precipitation of sediments in condensers or in corrosion of the mechanical components of the power plant.

The cooling system contains many devices made from various metals or alloys which form corrosion cells, while the cooling water acts as an electrolyte. The joint between copper and steel is particularly susceptible to electromechanical corrosion, as copper in the presence of sulphide, cyanide and ammonium ions may pass into the solution and precipitate, coating the steel surface and forming a cathode of a large area (Kirnbauer A., Freedman A.J. 1965). The intensity of electrolytic corrosion increases with the increase of water salinity. The presence of oxygen, carbon dioxide and dissolved salts, particularly chlorides, sulphides and sulphates, cause rapid galvanic oxygen corrosion. If the concentration of chlorides in the cooling water exceeds 150 mg/l, the steel faces the hazard of pitting, and the deep pits, despite their small diameter, may lead to piercing of the metal. High concentration of sulphate ions hinders the formation of protective layers on internal surfaces of tubes made from brass alloys. High pH may also lead to the destruction of the protective layer on the condenser tubes. A high concentration of calcium carbonates in the cooling water may cause the formation of deposits on wooden parts or in the fill of wet cooling towers. Their weight leads to the breaking off of individual components. Corrosion of nails and screws may also occur.

Local corrosion may be caused also by sediments formed by:

- chemical impurities in water
- suspensions in water
- microbiological vegetation

At different points in the facility, the sediments have a different porosity, at times resulting in pitting due to difficult access for air.

1.2 Equipment for Removal of Debris

The following devices are available to remove material from cooling water prior to the condenser:

- floating skimmers
- coarse grills
- fine grills
- traveling screens
- revolving drum screens
- siphon intakes

Most of the discussion of these devices that follows is drawn from Polish experience.

1.2.1 Floating Skimmers (Fig. 1)

Floating skimmers are situated on the shore line, across the inlet to the intake. The purpose of these skimmers is to protect the intake against the inflow of floating material of large size. The skimmers consist of a number of floating sections of several meters length, flexibly joined together. The floating sections may be made from metal floats joined together by means of a platform and also equipped with vertical trash bars. The length of the trash bars is approximately 1.0 m, and their spacing is 30 - 50 cm. The positioning of the skimmers should allow the floating material to continue down the river.

1.2.2 Coarse Grills

Coarse grills are common in water intakes for power plants. These grills are designed to stop large floating objects. They also protect the next, more sen filtration devices and cooling water pumps against the risk of damage.

In typical equipment configurations, the intake water passes through the coarse grills, and then through fine grills or mesh screens. In Hungary, however, some specialists recommend the use of these three grill sets:

- coarse grills with a bar spacing of 10 to 12 cm
- medium grills with a bar spacing of 3 to 5 cm
- fine grills with a bar spacing of 0.6 to 1.0 cm

Fine grills with mesh screens of 1 x 1 mm to 3 x 3 mm spacing, may also be utilized.

Coarse grills are usually constructed from a number of segments made from flat metal components joined together by means of braces. To facilitate cleaning, the segments of the grill are positioned at an angle of 15 degrees from the vertical, although vertical grills can be seen in older installations. The spacing of the grill bars is from 2.0 to 8.0 cm. In modern installations, the spacing of the bars is usually from 3.0 to 5.0 cm. Characteristic parameters of coarse grill construction are shown in Fig. 2 where:

α - angle of deflection of the grill from the vertical plane, usually equal to 15 degrees
h - height of the grill, m
b - width of the grill segment, m
c - spacing of the bars, cm

The dimensions of coarse grills used in several power stations are shown in Table 1. For the removal of rubbish trapped on coarse grills, grill cleaners are usually applied; they may be designed as stationary or traveling. Stationary grill cleaners are located on every span. One traveling cleaner may serve the whole width of the water intake.

The stationary grill cleaners have the following components:

- a scraper with a rake and devices for the control of operation
- a rubbish chute
- a belt or trough for the removal of the rubbish

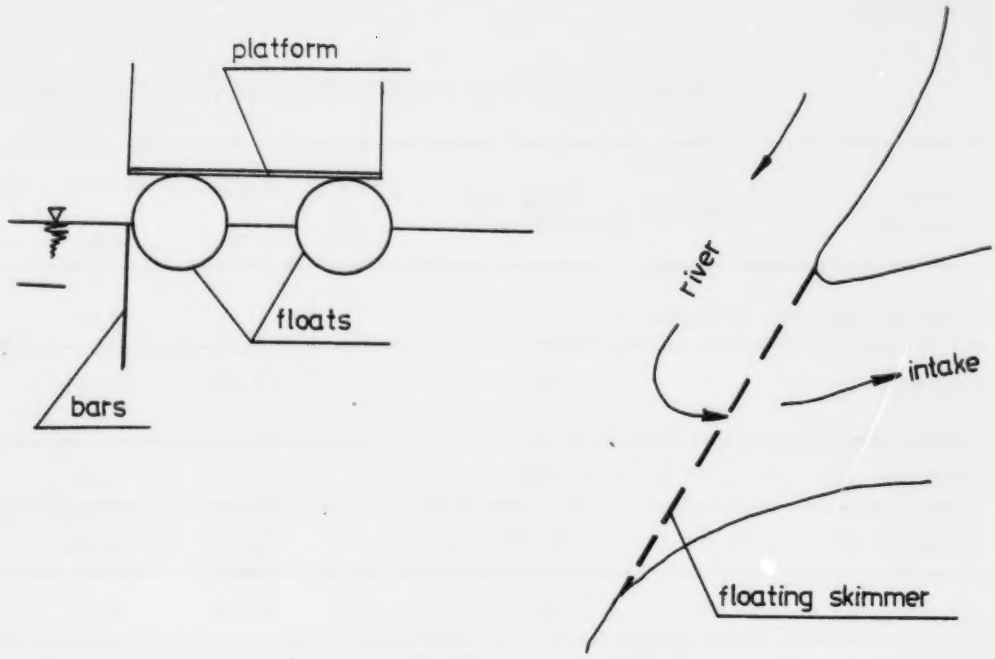


Fig.1. Floating skimmers

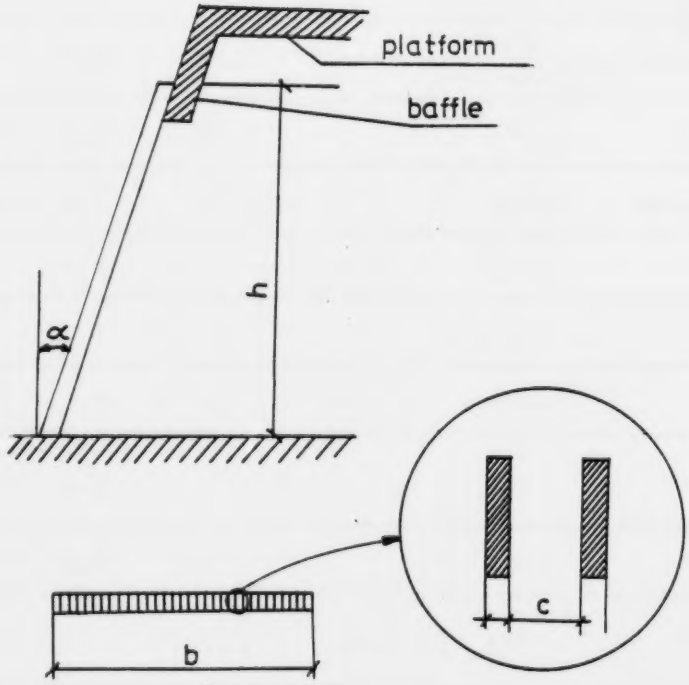


Fig. 2. Trash bars

Table 1

CHARACTERISTIC PARAMETERS OF COARSE GRILLS

Power Station	Country	Year of construction	height h /m/	width b /m/	mesh spacing c /cm/	Source of information
Starachowice	Poland	1950			5.0	
Patnow I	"	1967		3.70	4.0	Marianski /1978/
Patnow II	"	1967		3.12	4.0	"
Gdansk II	"	1970		3.12	4.0	"
Gdansk II	"	1973		2.40	3.0	"
Patnow II	"	1973		4.20	4.0	"
Patnow II	"	1973		2.10	3.0	"
Rhodos	Greece	1975		2.37	3.0	"
Siekierki II	Poland	under construction		3.00	2.0	"
Opole	"	"		2.14	2.5	"
Lacq-Artix	France	1956	4.15	2.11	7.2	Power plant Operators
Creil	"	1956	9.2		2.5	"
St-Ouen	"	1963			6.0	"
Montereau I	"	1959			8.0	"
Vaire sur Marne	"	1962			5.0	"
Montereau II	"	1964			5.0	"
Martiques - Ponteau	"	1971	9.12	4.0		"

In the operation of the grill cleaner, free upward and downward movement of the scraper is important, as well as a provision for the change of the rake position within a range of approximately 180 degrees. When the scraper moves downwards, the rake should be deflected from the grill face, while during upward movement, the rake should adhere to the grill. The speed of the scraper movement is usually within the limits of 1.5 - 2.0 meter/min.

Traveling cleaners are additionally equipped with a platform facilitating the movement of the cleaner, with a travel drive and with a truck for the removal of rubbish. A diagram of a traveling grill cleaner is shown in Fig. 3.

1.2.3 Fine Grills

Fine grills are used in older plants as the final screening devices. The basic construction of these grills is similar to that for coarse grills. The difference lies in closer spacing of the grill bars. The spacing of bars in a fine grill lies usually within the limits of 0.5 - 1.0 cm.

The delicate construction of fine grills is one of their major drawbacks. The need to minimize the bar spacing dictates that very fine bars be used. Such bars are quite fragile and are subject to mechanical damage. Serious problems are caused in fine grill installations by the use of elastic cleaning brushes. These brushes are ineffective in removing the material caught between the bars. Moreover, these brushes erode very quickly and require frequent replacement.

Because of the build-up of material on fine grills, the hydraulic resistance, usually kept at a level of approximately 10 cm, (periodically increases up to 50 cm or higher), causes damage to the grill and sometimes requires its replacement. Operating experience indicates that in the future fine grill design should consider the following items:

- High strength bars, resistant to mechanical damage, should be used
- Long bristle cleaning brushes which can extend to the entire depth of the grills
- Use of two rows of bars
- A mechanism which enables replacement of fine grills from the top to allow convenient rinsing with high pressure water streams and facilitates maintenance such as painting

It is expected, however, that even if these additional steps are taken, the difficulties discussed above may still persist. In Poland, fine grills have been replaced by traveling screens because of the above mentioned problems. It is envisioned that fine grills will be left only in one station (Pom Rzany plant near Szczecin) which has a power output of 240 MW. Satisfactory operation of fine grills in this power station is a consequence of the type of water intake utilized. Water drawn from the river is supplied to the power station by a wide channel operating as a sedimentation tank. The construction of these grills is similar to that used in other power stations. The spacing of the bars is 5 mm.

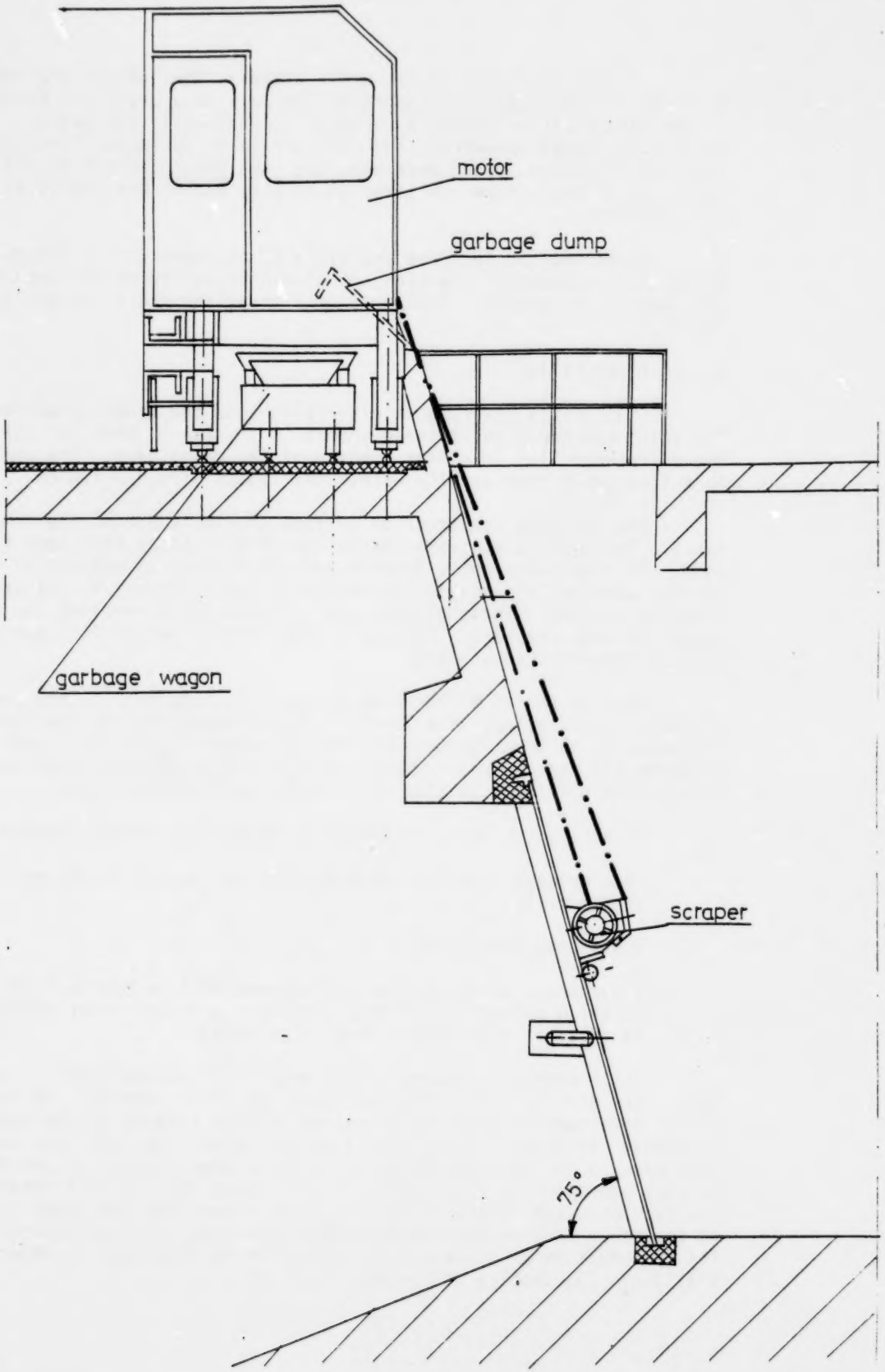


Fig. 3. Plan of mobile screen cleaner

1.2.4 Traveling Screens

Traveling screens were introduced in the 1950s with the development of medium and large steam power plants (above 100 MW). This action was necessitated largely by intake blockage due to increased water uptake and the use of large cooling water pumps. At first, two screens were used for each pump with the screens arranged either in parallel or in series. After some time, a standard design using one screen for one pump, was adopted. Diagrams of the construction location and operation of traveling screens are shown in Figures 4 and 5.

The basic components of traveling screens are cleaning baskets. They have the form of a frame with a tight mesh screen. The cleaning baskets are connected by means of articulated joints with driving chains, forming a closed, moving filtering belt. The belt speed depends on the purity of water and belt contamination. When the water and the filtering mesh are clean, the screens may be fixed. When the contamination of the filtering mesh increases, it must be put into operation and rinsed. Initially, screens with belt speed of approximately 2.5 m/min. were installed. Currently, screens with variable belt speed of 1.5 or 3.0 m/min. are installed. The usefulness of screens with infinitely variable belt speed is being analyzed. The mesh screen is usually made from bronze, phosphor-bronze or stilon, a synthetic fiber.

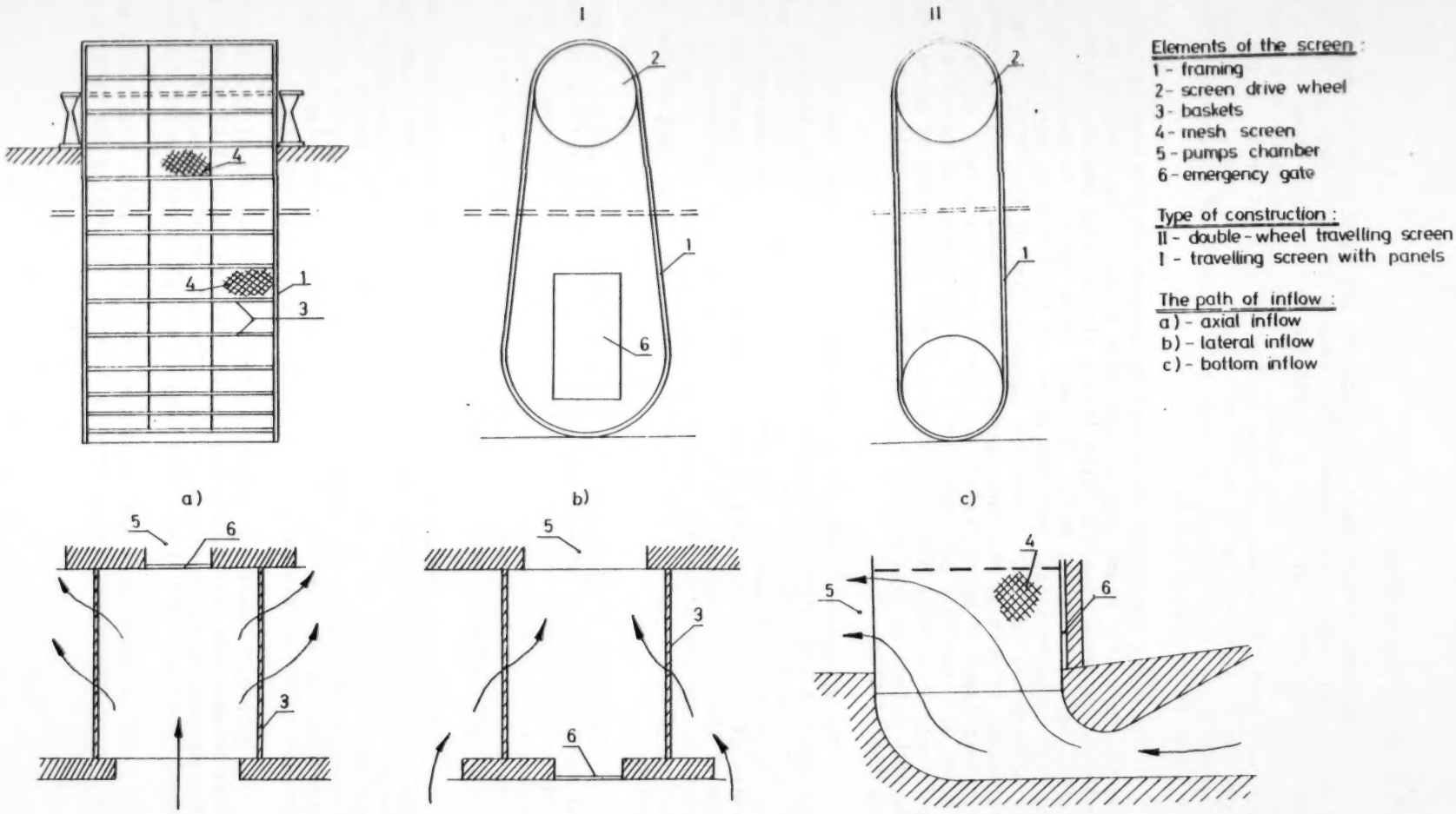
The diameter of the wire is between 0.6 - 1.2 mm. The size of the mesh opening lies within the limits of 2 x 2 to 10 x 10 mm, usually from 4 x 4 to 6 x 6 mm The surface area of the screens is usually sized $4m^2$ per 1 m $^3/s$ of filtered water. The water flow velocity is maintained within the limits of 0-3 - 0.5 m/s, but velocities exceeding 0.4 m/s occur when the surface of the screen becomes fouled. In most cases, the resistance of flow of water through the traveling screens does not exceed 10 cm. In general, the fouling of the screens is not permitted to exceed 30 per cent of the active surface.

Two types of construction are used: screens with panels (older types) and double-wheeled screens (newer types). Also, various inflows to the screens are used: axial inflow, bottom inflow, lateral inflow. Axial inflow screens are the most common. The water is directed to the interior of the screens flow to the sides and through the screen. Then the direction of flow changes and the water enters the pump structure.

Screens also include emergency gates which open automatically when excessive hydraulic resistance occurs. Such gates protect the screen against damage. Because the gates are used rarely and the time of operation with an open gate is short, no supplementary grills are installed behind them. The driving mechanisms of the traveling screens are usually located above the water level on the operators platform. Traveling screens also include nozzles for washing the screen and devices for the removal of debris.

Difficult operating conditions for the driving chains and the connections between the baskets and the chains are weak features of traveling screens. The component parts operate under water for prolonged periods of time. Under normal operating conditions, they require annual inspection and overhaul.

Polish experience has shown that in climatic zones with harsh winters the screen driving mechanisms require a casing protecting the screens against



Elements of the screen :
1 - framing
2 - screen drive wheel
3 - baskets
4 - mesh screen
5 - pumps chamber
6 - emergency gate

Type of construction :
II - double - wheel travelling screen
I - travelling screen with panels

The path of inflow :
a) - axial inflow
b) - lateral inflow
c) - bottom inflow

Fig 4 Action of travelling screens

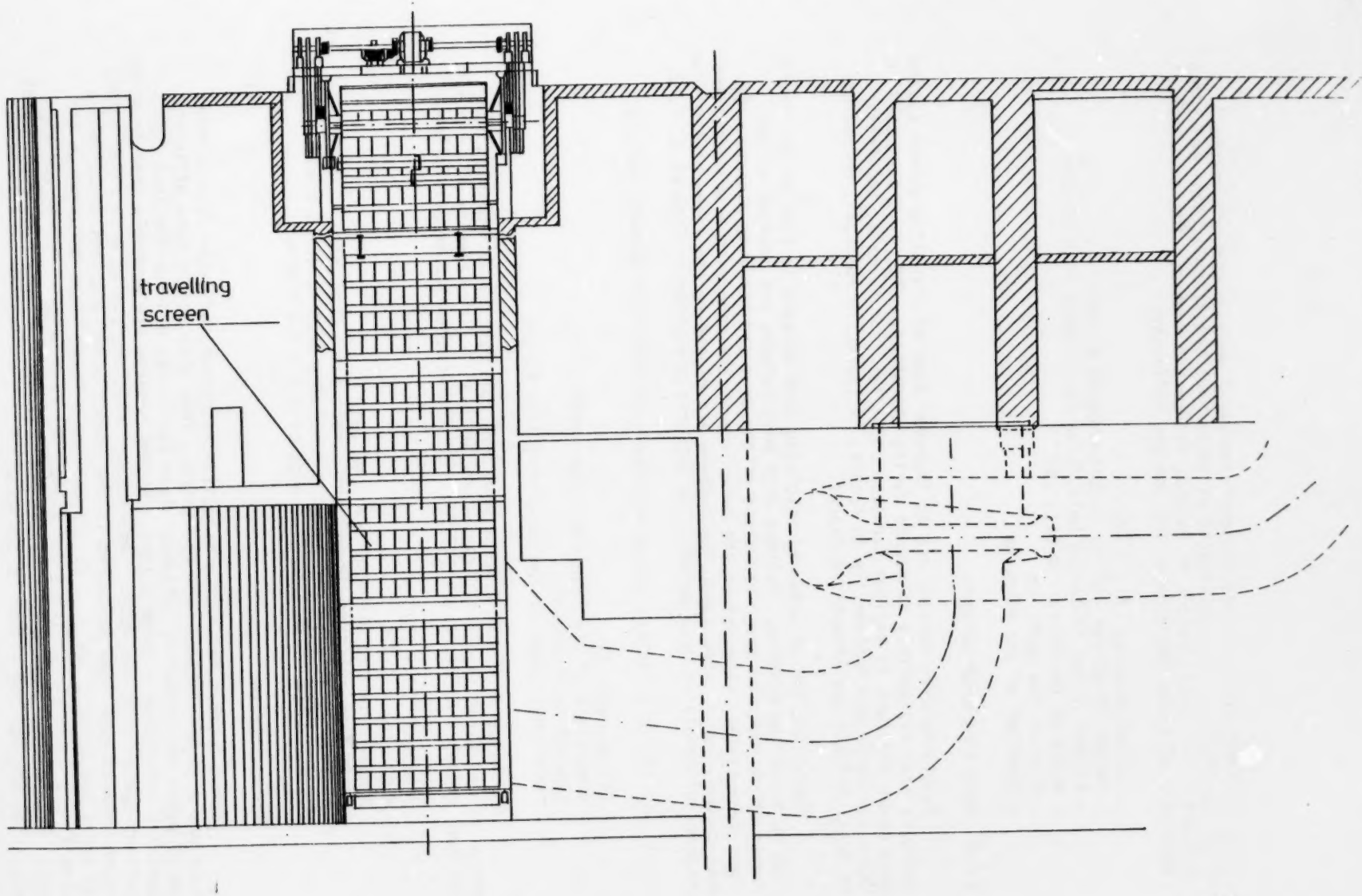


Fig. 5. Travelling screens at Havre Power Plant

icing in order to facilitate the performance of maintenance and overhaul in winter conditions. Characteristic parameters of traveling screens are shown in Table 2 for installations in Poland, France and Greece. The characteristic parameters of traveling screens include the following:

- inflow capacity (Q), M ^{3}/s
- height of screen /h/ for double-wheeled screens
- length of the filtering belt /L/,m for screens with slides
- width of the filtering belt /b/, m
- size of the mesh, mm
- diameter of the wire, mm

1.2.5 Revolving Drum Screens

Revolving drum screens are an improved type of traveling screen system which is less susceptible to damage during operation. They have been used in many power stations in various European countries; for example, Lac-Arctic, Vaire sur Marne and Porcheville in France, Carragado in Portugal, Northflect in Great Britain and Limasol in Cyprus.

The filtration of water by revolving drum screens is similar to filtration by traveling screens. Baskets with mesh screens are mounted on two wheels which form the basic structure of the drum and its side closure. Designs with baskets arranged on the periphery of the revolving drum screen are most common, but in some cases the baskets are placed on the sides of the drum. Diagrams of revolving drum screen flow patterns are shown in Figures 6, 7, 8.

The variable factors characterizing revolving drum screens include:

- inflow capacity
- dimensions of the revolving drum screen
- type of mesh screen
- rotational speed of the revolving drum screen

In Poland, revolving drum screens have not been used. However, the design of the first revolving drum screen with an inflow capacity of 10 m ^{3}/s has been proposed by Marianski (1977). Its characteristics are as follows:

- diameter (0) = 10.0 m
- width (b) = 2.4 m
- phosphor-bronze wires of 5 x 5 mm mesh
- water flow velocity through the screen 0.6 - 0.85 m/s
- maximum rotational speed of the revolving drum screen 6 m/min. with a range of rotational speeds of 1.2 - 6.0 m/min.

1.2.6 Siphon Intakes

Siphon intakes facilitate selective withdrawal of water from a given depth and a given distance from the shore. They also ensure more efficient use of pumps and screening systems. Such facilities provide for less contaminated water than a shore intake. Siphon intakes are commonly used in power stations cooled with sea water. Among power stations cooled with river water, siphon intakes have been installed in the French power stations at Cordemais and Vitry sur Seine (Fig. 9). In the Cordemais Power Plant situated on the Loire River, a design utilizing one siphon for each unit of 700 MW has been used. Each siphon draws 25.0 m ^{3}/s of water from the river. The velocity of water flow through the siphon is 3.0 m/s.

Table 2

CHARACTERISTIC PARAMETERS F ROTARY SCREENS x/

Power Plant Country	Year construction completed	Traffic capacity /Q/ m³/s	Height of screen /h/, m	Lenght of belt /l/, m	Width of belt /b/, m	Size of mesh mm	Diameter of mesh ø, mm
1	2	3	4	5	6	7	8
Stalowe Wola Poland	1960	3,1				4 x 4	
Patnów I Poland	1967	8,3		21,0	2,69	1 x 1	0,4
Gdańsk II Poland	1970			15,0	1,20	1 x 1	0,5
Wrocław II Poland	1970			22,0	1.22	1 x 1	0,5
Łybnik Poland	1972	8,3		25,0	2,69	5 x 5	1,2
Ostrołęka Poland	1973	8,3		29.0	2.69	1 x 1	0.5
Gdańsk II Poland	1973			23.0	2.69	1 x 1	0.5
Patnów II Poland	1973	8.3		23.0	2.69	5 x 5	1.2
Połaniec Poland	1975	8.3		29.0	2.69	5 x 5	1.2
Kozienice- Łaz Poland	1977			18.0	0.90	2.5 x 2.5	0.8
Jaworzki V Poland	In construction			17.0	0.70	5 x 5	1.2
Kozienice Poland	"	8.3		28.0	2.70	5 x 5	1.2
Turów Poland	"			20.0	1.80	1.6 x 1.6	0.8
Połaniec Poland	"	8.3		31.0	2.70	5 x 5	1.2
Bełchatów Poland	"			19.0	2.70	3.2 x 3.2	1.1
Rhodos Greece	1975			16.0	1.80	2 x 2	1.0
Creil France	1956		7.75		3.00	0.56 x 0.56	
Montes Cheviré France	1958	3.3		38.4		6 x 6	
Montreau France	1959	4.5				4 x 4	
Champagne sur France Oise	1961	9.75				4 x 4	
St. Ouen France	1963	10.0				3.17 x 3.17	
Blénod France	1963	5.65	9.75		2.15		
Le Havre I France	1968	10.0					
Le Havre II France	1969	20.0					
Cordemais France	1970	2.5		18.4	4.10		
Martigues Monteau France	1971	9.0	9.12		4.00		

x/ screen parameters in Polish power plants are given by Kaniadmi /1978/.

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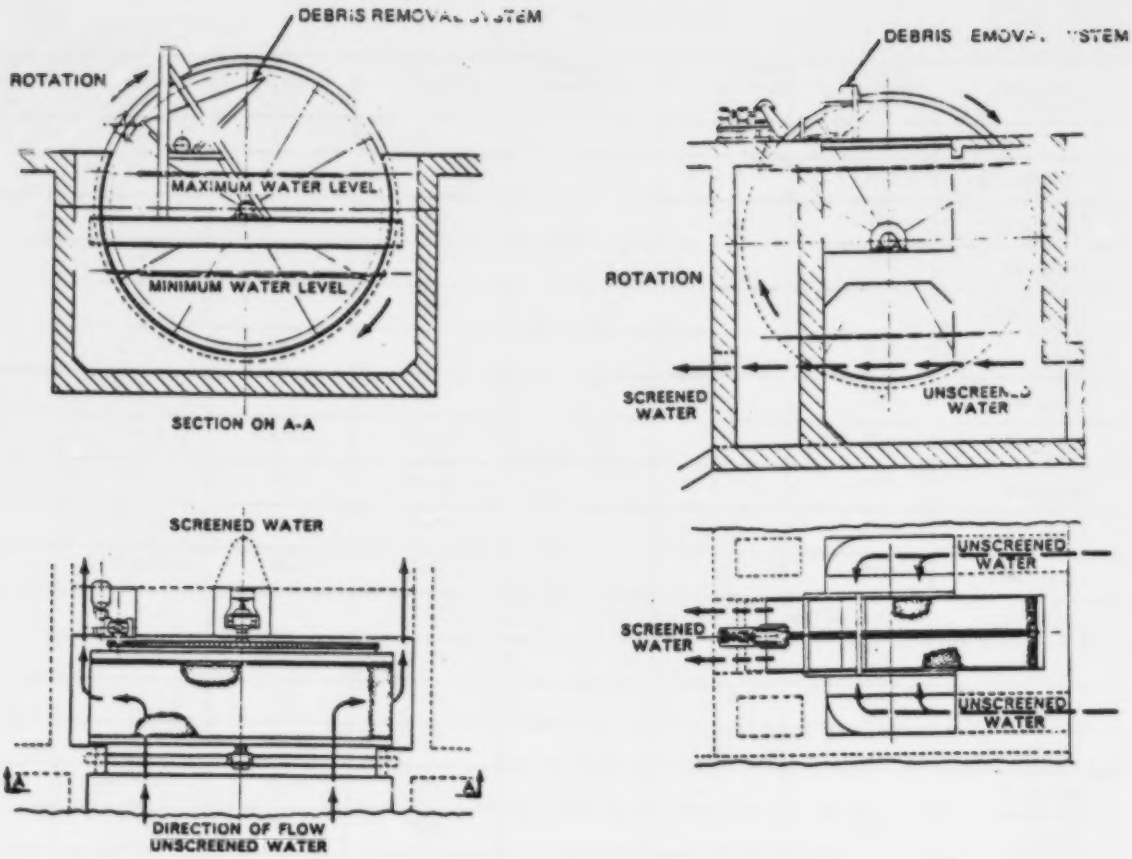

Single entry cup screen

Double entry cup screen

Fig.6. DIFFERENT WAYS OF WATER IN FLOW THOUGH THE REVOLVING DRUM SCREENS

/by Development Document for Proposed Best Technology Available for Minimizing Adverse Environmental Impact of Cooling Water Intake Structures.U.S.Environmental Protection Agency.Washington.D.C. EPA 440/1-74/015.December 1973. 175 p./

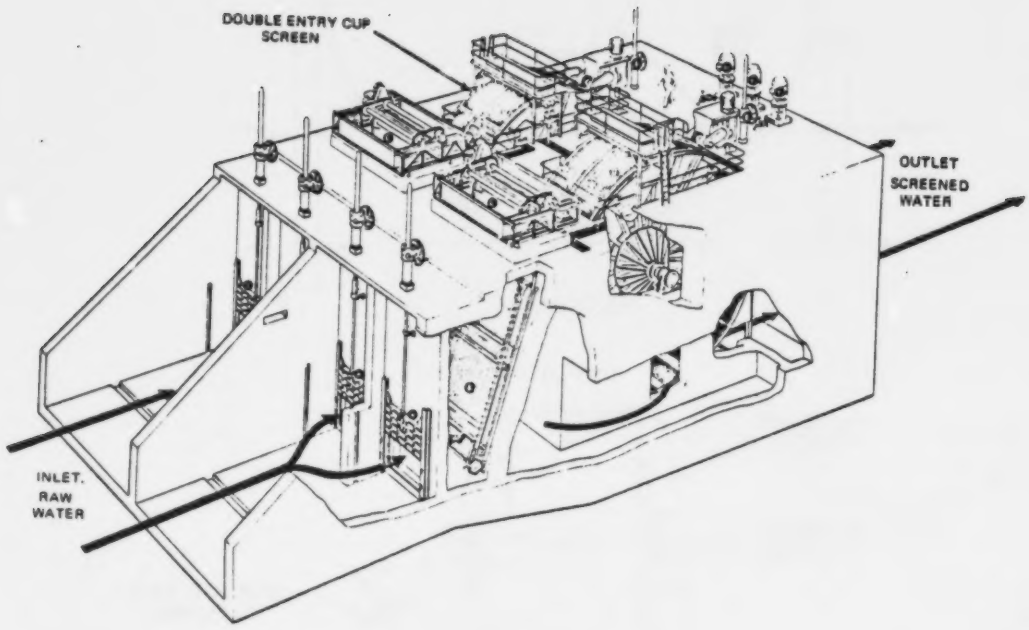

Figure 7. Screen structure with double entry cup screens

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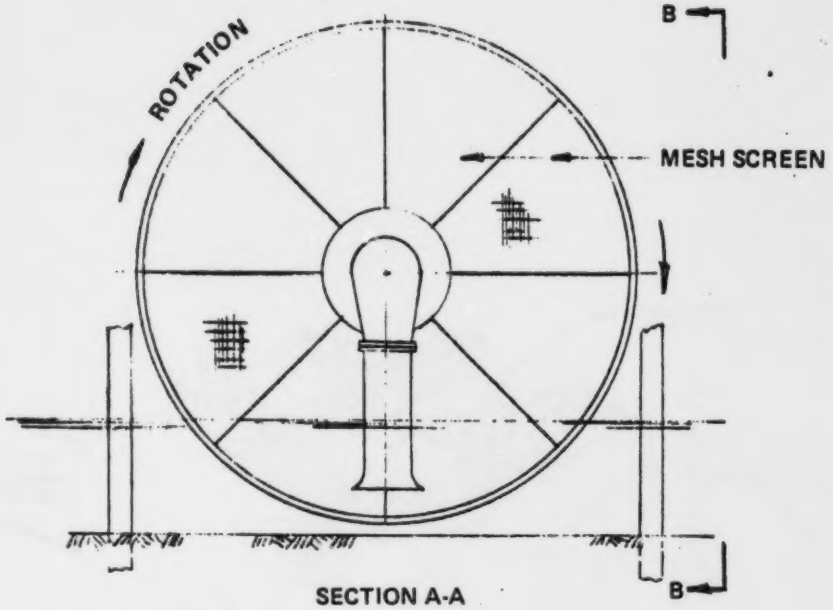
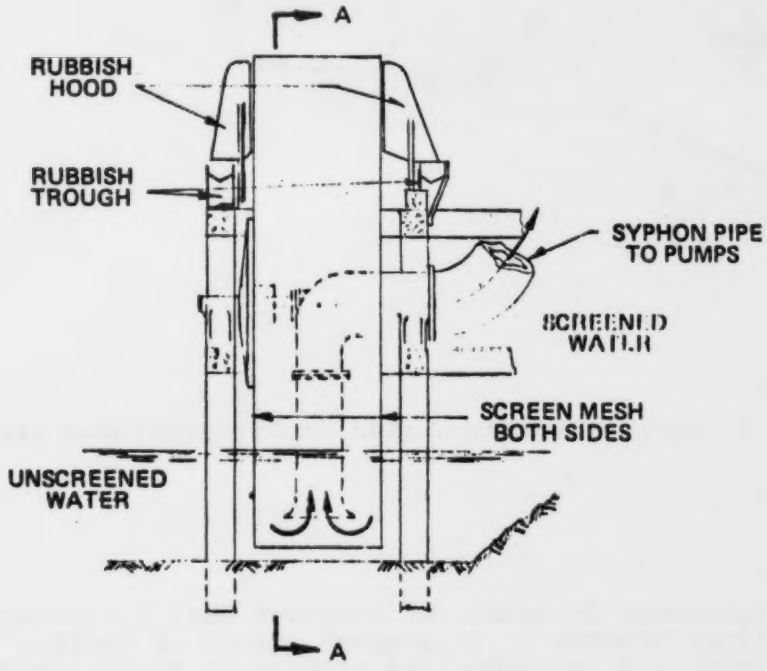


SECTION A-A

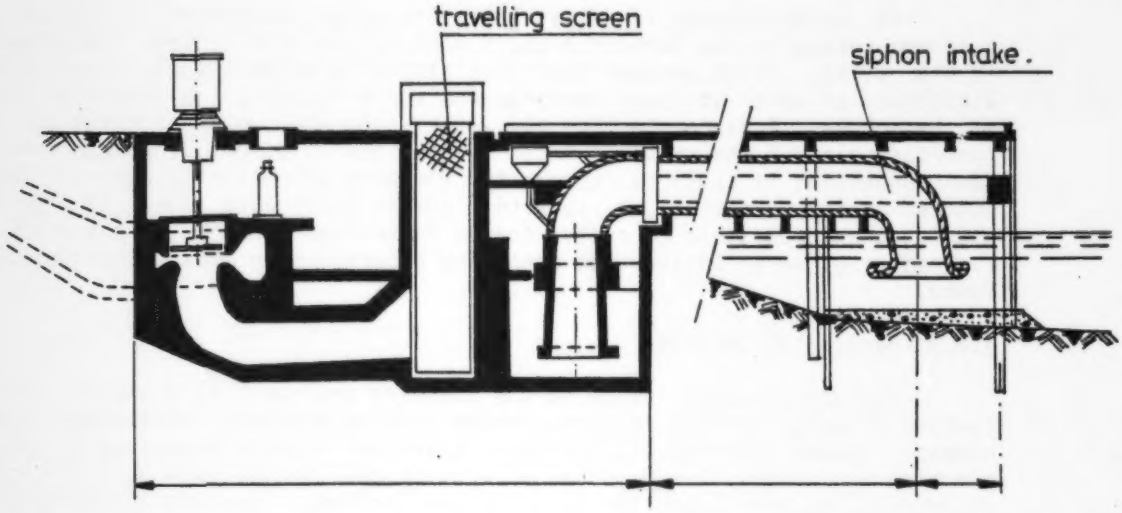


ELEVATION B-B

FIGURE 8. DOUBLE ENTRY DRUM SCREEN OPEN WATER SETTING

/by Development Document for Proposed Best Technology Available for Minimizing Adverse Environmental Impact of Cooling Water Intake Structures. U.S. Environmental Protection Agency. Washington, D.C. EPA 440/1-74/015. December 1973. 173 p.

a)



b)

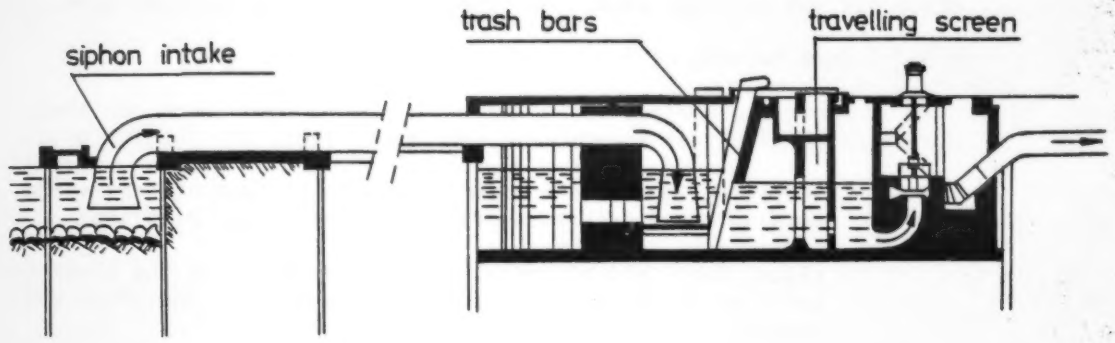


Fig. 9 . Siphon intakes at French Power Plants

a) Cardemais

b) Vitry Sur - Sein

1.2.7 Shaft intakes

For water intakes in deeper lakes and water reservoirs, our proposal is a siphon intake in the form of a shaft with bottom water intake (as presented in Fig. 10 a). It is assumed that this kind of equipment would enable the withdrawal of water at lower temperatures while reducing the number of fish at the intake. A cap protecting the intake from the top constitutes an important part of the system. A cap in the form of a movable platform has been suggested; it could be removed for cleaning of collected debris. Another suggestion is to provide the cap with a coarse grill with hooks. The grill should make it possible to remove coarse impurities settling on the bottom in the region of water intake. No operating experience on this technique was found.

1.2.8 Horizontal Intakes

Horizontal water inflow to the cleaning equipment is a characteristic feature of water intakes in once-through cooling systems. Horizontal flow, however, causes considerable inflow of trash and aquatic organisms to the cleaning equipment. Our proposal of a horizontal intake with vertical water filtration has been suggested to avoid the problem. Fig. 10b illustrates this kind of equipment.

The filtration pond, protected at the inlet by a coarse grill, is the basic element of the horizontal intake. A mesh screen, with about a 5 x 5 mm mesh size, constitutes the floor of the pond. Collection chambers under this screen deliver water to a return basin and then to the pumps. The area of the filtration pond should ensure the water filtration rate of $V<10$ cm/s. The pond should be segmented to allow service for routine cleaning and replacement of the mesh screen. In addition, horizontal intakes include skimmers and methods of removing floating trash. Horizontal intakes minimize the mass of material flowing to the condenser and protect adult fish, as well as fry. This technique has not yet been used. No operating experience is available.

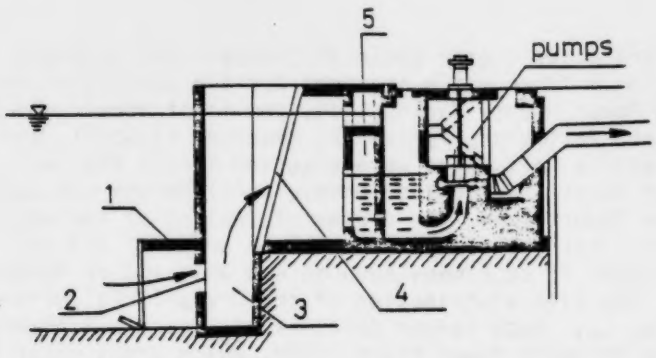
1.3 Some Methods of Biological Pollution Control

Among the various biological fouling problems which can hinder the operation of the steam power plant cooling systems, are the following:

- shellfish, which form colonies on the surface of intake and pumping stations structures and on the intake pipelines
- algae, fungi and bacteria, which grow mainly in the condensers and also on the surface of cooling tower fill and other components

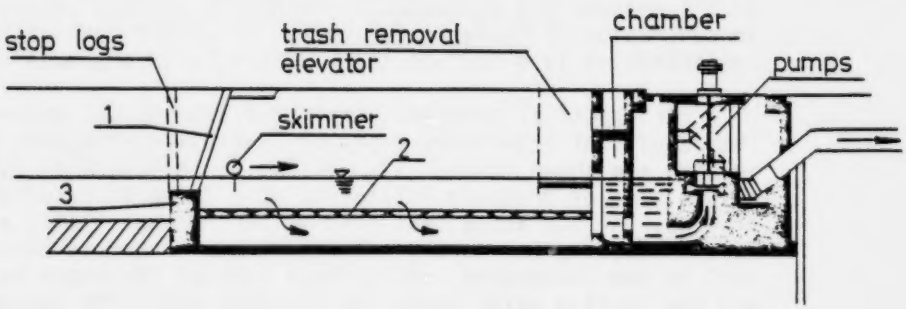
Colonies of shellfish can be particularly troublesome in sea water intakes. In Central and Eastern Europe, the fouling by shellfish of water intakes from lakes and reservoirs can cause serious problems. Specifically, the presence of the shellfish Dresseia Polimorpha in stagnant water, is troublesome. This shellfish originates from the catchment area of the Black Sea and Caspian Sea and has been spread by commerce to a much larger scale. Under natural conditions, the larval hatching period lasts from June until August. Larvae of Dresseia Polimorpha swim freely, but adults are sedentary. Operation of once-through cooling systems causes elevated temperatures which

a) shaft intake



1 - cap
2 - inlet
3 - shaft
4 - coarse grill
5 - travelling screens

b) horizontal intake



1 - coarse grill
2 - horizontal screen (5×5mm size of the mesh)
3 - debris log

Fig.10. Shaft and horizontal intakes

accelerate the growth cycle of Dresseia Polimorphea. For example, on the five Konin lakes which are used for the cooling of the Patnow and Konin Steam Power Plants during 1970, the first appearance of the slowly swimming Dresseia Polimorpha larvae was observed in April, and by May large numbers of Dresseia Polimorpha were observed in all the Konin lakes. In May, fouling of intake surfaces by Dresseia Polimorpha was noted. In 1969, at the Patnow Power Plant, the degree of fouling of the water intake was observed on artifical substrate with surface areas of 100 cm^2. On September 23, 1969, the number of specimens counted was 381; and on November 11, the number was 364. The size distribution of the Dresseia Polimorpha specimens are shown in Fig. 11. Much larger colonies of Dresseia Polimorpha have been found in the Moldavia Power Plant, USSR, which draws water from the Kuchurganski reservoir. Research conducted in July 1968, Swierdlow, et al., 1970, disclosed the following:

- layer of mussels, 25 - 50 mm thick
- weight of the wet mass of fouling, 3.6. - 4.0 kg/m^2
- number of Dresseia Polimorpha specimens, 90,000 - 200,000/m^2

Colonies of Dresseia Polimorpha were covering all moving and stationary parts of the intake immersed in water. Biological research regarding the development of Dresseia Polimorpha shows that fouling should be controlled twice in a year: during the spring (in May) in order to destroy the wintered forms,and in the fall (in October), in order to destroy generations of the current year. In order to find optimum methods for the control of Dresseia Polimorpha, various chemical agents and thermal methods have been laboratory tested. Because of the high tolerance of Dresseia Polimorpha, chemical agents have proven unsuitable for its control. For example, attempts to control Dresseia Polimorpha by means of copper sulphate $CuSO_4$ have shown that the lethal concentration of $CuSO_4$ at 12.5°C is 24,300 mg/l. This dose is reduced as the temperature increases and the lethal concentration at 27.5°C reaches 300 mg $CuSO_4$/l. In Polish surface water, the permissible concentration of $CuSO_4$ is 0.3 mg/l. If copper ions are used, the lethal concentration is 4 mg/l Cu at 20-22°C with an exposure time of 48 hours.

For practical purposes, thermal treatment has proven to be more efficient. The results of laboratory tests of controlling Dresseia Polimorpha by water heating are shown in Fig. 12. According to Swierdlow (1970), the lethal exposure time of Dresseia Polimorpha at a temperature of 40-49°C is 3 - 15 minutes. At the above mentioned Moldavia Power Plant, a thermal control method for Dresseia Polimorpha has been used. Water is heated to a temperature of 50°C in the condensers, while the output of the plant was reduced by one half and the cooling water pumps are switched off. The heated water is directed immediately to the intake.

A similar method has been applied for control of the growth of shellfish in the Bulgarian Warna Power Plant using the saline water of Warne Lake for cooling. To prevent fouling, water heated up to 45°C is recirculated to the intake. The procedure is repeated once a month during the spring and summer. The first hot water release takes place in April or May. An exposure time of 50 minutes is used.

Similar methods of control of Dresseia Polimorpha and other shellfish have been used at other power plants. The degree of heating and the time of exposure of each species of fouling organisms needs to be determined.

For example, some water organisms such as Mytilus Edulis and barnacles,

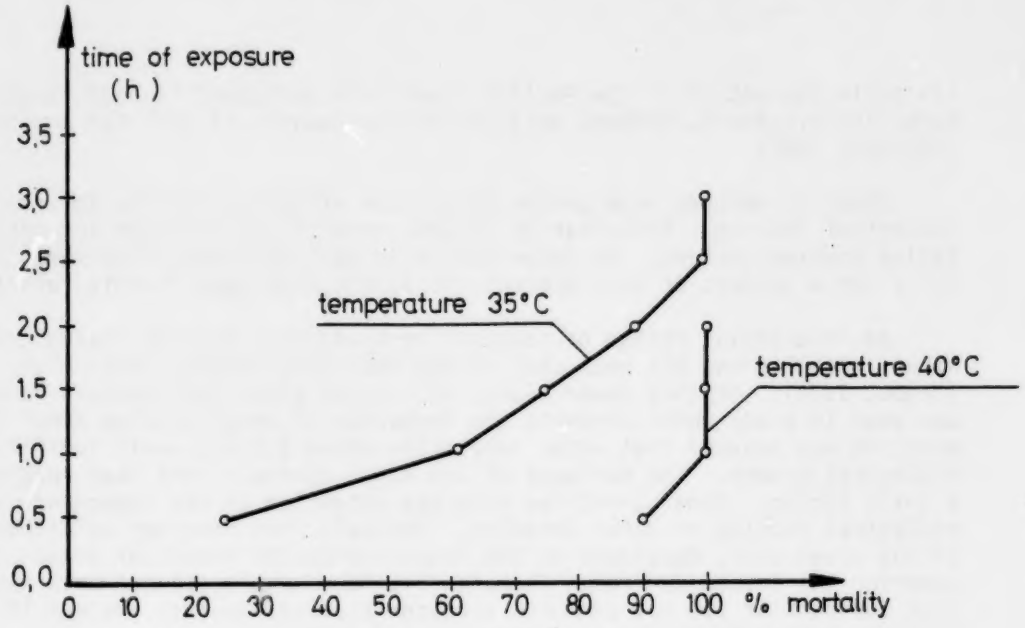


Fig. 12 Mortality of Dreissenia Polimorpha in function of time

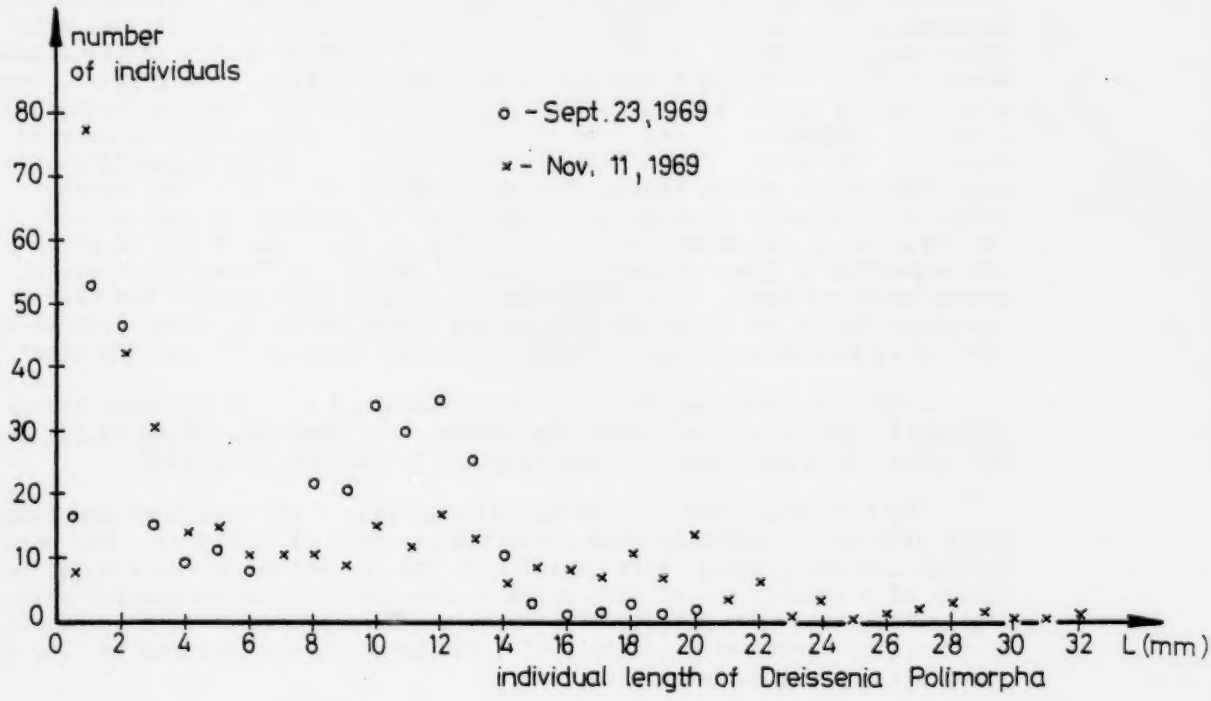


Fig. 11 Overgrowing of surface at Pątnów Power Plant (Dreissenia Polimorpha)

living in the waters of the Pacific Ocean, are resistant to high temperatures and withstand, without serious harm, exposures of 38°C for one hour (Mininmi, 1967).

Chemical methods have proven to be more effective for the control of biological fouling. Chlorination is used both in once-through and recirculating cooling systems. As chlorination is well discussed elsewhere, and it is not a subject of this project, it is not discussed in this report.

An interesting method of controlling biological fouling inside cooling water installations has been used at the Hartiques Ponteau Power Plant (Magou, 1971). In this power plant, all closed pipes and channels have been designed in a way which prevents the formation of areas of slow water movement; it was assumed that water velocities above 2.0 m/s would inhibit biological growth. The surfaces of the water channels have been covered with a toxic lining. Other countries also pay attention to the dependence of the biological fouling on water velocity. The safe flow rate may be different in any given case, dependent on the requirements for growth of organisms covering the intake surface. In Bulgaria, for example, it has been assumed that the rate of 2.0 m/s protects surfaces against fouling, whereas in the USSR the safe rate has been assumed to be 3.3 m/s.

1.4 Control of Chemical Impurities

The control of chemical impurities is relatively easy in closed cycle systems where make-up water may be treated chemically. However, in once-through cooling systems, such treatment is practically impossible. It seems that at present the only available method for control of chemical impurities in oncethrough cooling systems is the use of CEPI devices installed on endangered pipe. The CEPI apparatus is composed of a cylindrical body with strong magnets inside. Chemical impurities flowing through a strong electromagnetic field lose their ability to form macrocrystals. The crystals separated from the water flowing through the electromagnetic field disintegrate forming a suspension in the form of soft sludge or slime which is carried away with the water. The action of the CEPI apparatus has a purely physical character and is not connected with any chemical reaction. The chemical composition of water remains unchanged, and its hardness is not reduced. The duration of the magnetic induction effect, i.e. the period in which the magnetically caused potential change prevents the formation of scale, is approximately 3 days. This means that in once-through systems the CEPI apparatus has to be installed only in one place, while in closed systems the CEPI units should be installed both in make-up water and in cooling water.

The CEPI units may be installed in water of a salinity lower than 3000 mg/l, and in systems where the thermal load does not exceed 25,000 kcal/h. CEPI units have been used in industrial installations since 1945.

Up till now, over 100,000 units of various sizes have been manufactured. Units produced in quantity have a maximum capacity of 8000 m^3/h. For once-through cooling systems, this capacity is too low and would require the installation of a special set of CEPI units or the construction of special units of high efficiency. The details of construction and operation of these units are protected by Vermeiren's patent. CEPI equipment is manufactured by S.A. Euprex-Antwerpia, a Belgian enterprise.

1.5 METHODS OF CLEANING CONDENSERS

1.5.1 Mechanical Removal of Deposits

The most common mechanical method of protecting the internal surface of condenser tubes against the formation of deposits is the continuous passage of elastic rubber balls of a diameter larger than the diameter of the condenser tubes. The system consists of devices for collecting the balls from the condenser outlet and sending them to the inlet chamber of the condenser.

Two types of balls are usually used: smooth balls and balls with an abrasive surface. However, both these types of balls have a number of drawbacks. This is caused by the nature of the sediments precipitating in the tubes. These sediments usually have a non-homogeneous thickness and chemical chemical composition, which results in non-homogeneous hardness and adhesion to the tube walls. In such cases, the use of balls with an abrasive surface can cause selective local abrasion of the condenser protective layer. In extreme cases, this can lead to leakage of tubes, especially those with surface deformations.

On the other hand, spongy balls, because of their highly developed soft surface, quickly become abraded and their dimensions are reduced, causing the need of frequent replacement. The high elasticity of spongy balls also requires the installation of complex screens catching the balls after the condenser in order to return them to the cycle.

To eliminate these drawbacks, a new technology of balls production has been developed in Poland and has been used at the Skawina plant and other facilities. The balls are made of a spongy mass, permeable to water and characterized by a rigid and rough surface formed in special patterns. This facilitates delicate and effective abrasion of sediments from the tubes surface, without any damage to the condenser tubes. Initial experiments show that these balls fully prevent deposits from accumulating on the tube surface and reduce chemical scaling to a high degree. It is believed that the use of balls will reduce the necessity of chemical cleaning of condensers to only once every three or four years. The installation of the system for continuous condenser cleaning by means of rubber balls can also reduce the temperature of the steam condensate by several degrees centigrade.

1.5.2 Chemical Cleaning of Condensers

Chemical cleaning of condensers aims at the removal of deposits and formation on internal tube surfaces or protective layers, preventing corrosion and precipitation of deposits. Because of the use of compounds that are harmful to the environment, chemical cleaning of condensers is usually performed only in closed system cleaning installations. The frequency of cleaning depends on the rate of accumulation of deposits. In most cases, such cleaning is performed once a year, at the start of normal unit maintenance. If systems of cleaning by means of balls are in use, chemical cleaning may be limited to only once every 2 or even 3 years. If water is strongly contaminated, cleaning may then be necessary twice a year. The total time for cleaning amounts to 20 - 24 hours. The effect of chemical cleaning is presented in Fig. 13.

Although this method effectively removes mineral deposits, it causes corrosion of the condensers by dezincification of brass. This fault was eliminated by the introduction of a nitrogen shield. The method consisted of displacement of air by nitrogen introduced under pressure (Fig. 14).

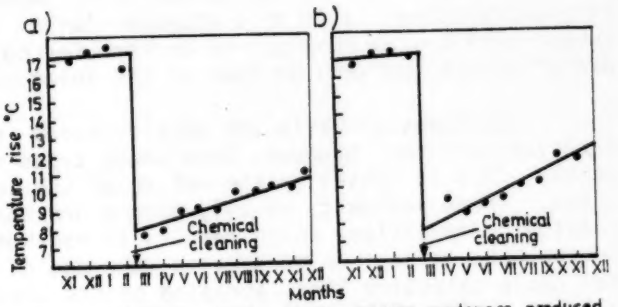


Fig. 13. Effects of cleaning of the 55 MW condenser produced by Siemens Comp.

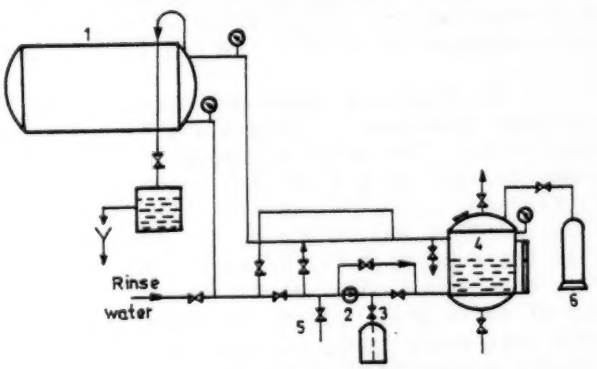


Fig. 14. Installation for the rusted pipes of the condenser chemical cleaning

1 - condenser; 2 - circulating pump; 3 - acid cylinder; 4 - tank; 5 - outlet pipelines; 6 - nitrogen cylinder

The oxygen-free atmosphere significantly limits the process of corrosion and increases the effectiveness of cleaning.

The next development in the cleaning of condensers involves the use of fatty acids for cleaning. For cleaning, an addition of fatty acids with the trade name of "Kowod" is used. The amount of the acid by weight depends on the quantity and quality of the sediments on the tubes. Small amounts of hydrochloric acid, glucose and hydrazine are added to the acid as agents which heighten the effect of cleaning and reduce the corrosive action of the solution (Jakubik, Maciejewski 1976). Neutralization is achieved by using a diluted solution of sodium carbonate and phosphate. An aqueous solution containing H_3BO_3, $KMnO_4$ and $FeSO_4$ is used to coat the surface. In Polish power plants, the common practice of cleaning the condensers by this method ensures good cleaning and high smoothness of the cleaned condenser surfaces; thus, longer periods occur between cleaning operations.

As "Kowod" is a product produced on a small scale, another chemical product "Emulkator" has been introduced for industrial application. Chemical cleaning of the condenser tubes by means of "Emulkator" is similar to that in the case of "Kowod".

Some types of sediments and impurities require additional treatment. In the case of compacted sediments with a low level of calcium carbonate, chemical cleaning must be preceded by thermal treatment (heating to 55-60°). Because of differential linear expansion of the metal and sediments, the heating leads to the cracking and loosening of the sediments, and therefore facilitates the penetration of the acid. If organic substances or particles of coal and dust are present on the surface of mineral deposits, then the tubes should be cleaned by a hydraulic method prior to chemical cleaning.

If the surfaces of the condenser tubes are contaminated with oil or other petroleum derivatives, the tubes should be washed first with a warm solution of sodium phosphate and carbonate with the addition of detergents such as Sulfapol or Alfenol, with simultaneous hydromechanical cleaning of tubes using solution. After such preliminary preparation, chemical cleaning is performed. In some cases, the cleaning cycle will need to be repeated several times.

2. IMPACT OF OPEN AND CLOSED COOLING SYSTEMS ON SURFACE WATER QUALITY

The impacts of the operation of a steam power plant on surface water quality may be divided into two groups:

1. Impacts other than those associated with cooling systems
2. Impacts associated with cooling systems

The first group of problems are a result of faulty operation and maintenance or shortcomings in design and construction, for example:

- lack of proper protection against discharges of oil and grease
- improper design of sewerage systems and sewage treatment systems
- lack of equipment for treatment of toxic compounds arising from the processes within the power plant

This group of problems may also include changes caused by power plant construction and ash storage. In Polish experience, drainage at the construction area results in uniform decreases of groundwater level, sometimes reaching several centimeters and covering an area of a few square kilometers. After construction is finished, the groundwater may need to be kept at a lower level by pumping.

Changes of the hydrogeological regime in the area of the ash pond are caused by infiltration of runoff waters into the earth. Since these waters may include various harmful or toxic compounds which are leached from the ash, the situation requires careful analysis. The problem is particularly important if the ashpond is located near groundwater or surface water used for public water supply.

The second group of problems include those mainly connected with cooling system operation. Previously, much attention has been placed on thermal problems connected with open cooling system operation, particularly on ecological changes. Lately, more attention has been given to the impact of cooling system operation on surface water quality.

Open and closed cooling systems have somewhat different problems. Sources of water pollution from open cooling systems can be: corrosion, chlorination, and chemical compounds used for condenser cleaning. Closed cooling systems have various additional sources:

- Concentration of cooling water compounds caused by evaporation in cooling towers
- water treatment for cooling purposes
- protection against precipitation
- use of corrosion inhibitors
- use of special means of protection against growth of water organisms in cooling system installations
- wash-out of pollutants from the air by cooling towers

Concentration of compounds found in cooling water, blowdown water, and sewage are usually low; however, even these concentrations of heavy metals and toxic compounds can be dangerous in the environment. Heavy metals such as Hg, Zn, and Cr accumulate in sediments and aquatic organisms. Bioaccumulation can lead to toxic concentrations in higher trophic levels.

This discussion describes previous Polish research and the results of

research carried out for the purpose of this report. Fig. 1 presents the location of the Polish power plants that were investigated.

2.1 Open Cooling Systems

Broad research on water quality in open cooling systems and the impact of steam power plants with open cooling systems on surface water quality has been carried out in France. Measurements were made in 1964 at the Vaire-sur-Marne power plant. The results of those measurements showed that, except for some changes in nitrite content, the power plant had little effect on water quality.

2.1.1 Discussion of Project Results for Open Cooling Systems

To evaluate the changes in cooling water quality at local power plants with open cooling systems, results of studies carried out by the Institute of Meteorology and Water Management (IMWM) between 1972 and 1977 at the Kozienice, Stalowa Wola, Dolna Odra, and Ostroleka power plants are used (9,10,11,12,13). Measurements at the Gdansk, Rybnik and Skawina power plants were carried out during the 1975-77 period (14,15,16,17,18) and continued in 1978-79 by the IMWM Water Management Division (WMD). Samples were taken considering the transport time of cooling water through the cooling system.

In Tables 3 and 4 a comparison of frequency of occurrence of positive and negative differences between intake and discharge quality is made. A plus sign indicates the concentration was higher at the discharge than at the intake.

The analysis of basic parameters of cooling water quality indicates that changes occur mainly for nitrogen compounds:

- The content of nitrate compounds in cooling water does not significantly change except for the Kozienice power plant, where the increase of nitrate concentration was observed in 22 of 39 samples taken.

- Nitrite concentration appears to increase as a result of passage through the cooling system. In 33 of 41 samples taken at the Kozienice power plant, nitrite concentration increased at the point of discharge. This trend of increase in nitrite concentration was also indicated by measurements taken at the Dolna Odra and Ostroleka power plants. Analyses of water at the Gdansk power plant show a decrease of nitrite content at the discharge in 10 of 12 samples taken.

- Decrease of ammonia nitrogen content was observed at the Rybnik and Gdansk power plants; however, at the Stalowa Wola and Ostroleka power plants, the content of ammonia nitrogen in the cooling water increased.

- A small increase of organic nitrogen content was observed at the Stalowa Wola and Ostroleka power plants, but measurements taken at the Kozienice power plant do not show this phenomena.

- In 5 of 6 power plants under investigation, a small decrease of BOD_5 is observed in water after passage through the cooling system.

- At the Gdansk and Rybnik power plants an increase of COD was observed.

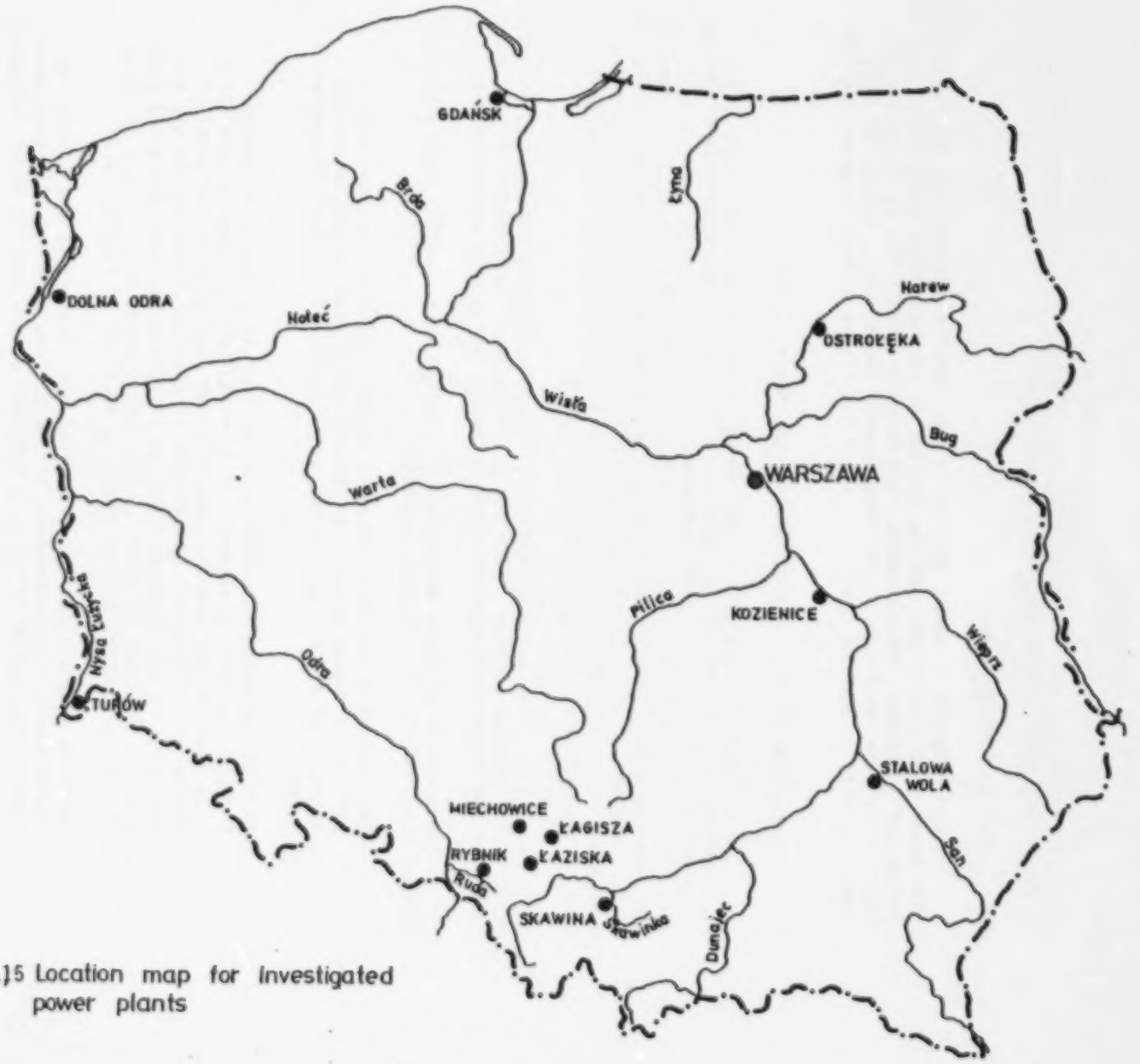


Fig.15 Location map for investigated power plants

Table 3. Comparison of changes of cooling water quality chemistry between intake and discharge in Polish power plants with open cooling systems

Power Plant	Kozienice			Stalowa Wola			Dolna Odra			Ostrołęka		
Indicator	No. of samp.	Change		No. of samp.	Change		No. of samp.	Change		No. of samp.	Change	
		-	+		-	+		-	+		-	+
Reaction (pH)	40	13	15	5	3	11	14	5	2	8	1	4
BOD	41	24	16	5	4	1	14	8	5	8	5	3
COD	41	20	21	5	2	3	14	8	4	8	5	3
Ammonia	41	18	18	5	1	4	9	4	3	8	3	5
Nitrite	41	5	33	5	3	2	14	1	8	8	2	5
Nitrate	39	16	22	5	4	1	14	5	8	8	2	5
Org. nitrogen	41	24	17	5	0	5				8	2	5
Orthophosphates	41	22	17	5	4	0	14	6	6			
Org. phosphates	40	20	20							8	2	5
Dissolved solids							14	7	5			
Suspended solids							14	7	6			
Conductivity	41	13	18	5	1	2				8	3	2
Period frequency of research	Feb.73-Dec.75 twice a month			Oct. 75-July 76 every second month			Apr.75-Oct.77 every second month			Aug.72-Oct.77 once a month		

During the day of sampling, 10 l samples were taken once a day. Ranges of changes in concentration were several times higher than the accuracy and sensitivity of measurments.

Table 4. Comparison of changes of cooling water quality chemistry between intake and discharges in Polish power plants with open cooling systems

Power plant	Gdańsk			Rybnik			Skawina		
Indicator	No. of samp.	Change		No. of samp.	Change		No. of samp.	Change	
		-	+		-	+		-	+
pH	12	4	8	9	4	5	10	1	5
BOD	12	10	2	9	3	6			
COD	12	4	8	9	2	6	10	6	4
Ammonia	4	3	1	9	8	0	9	2	6
Nitrite	12	10	2	9	4	5	7	4	3
Nitrate	4	3	1	9	4	5	9	5	4
Org. Nitrogen	12	5	3	9	2	1			
Sulphates	12	5	7	9	5	4	10	8	2
Chlorides	12	5	7	9	3	4	10	6	4
Phosphates				7	3	3	10	2	8
Alkalinity	11	4	7	9	3	2	9	0	5
Hardness	12	6	6	9	2	6	10	3	6
Dissolved solids	12	5	7	9	5	4			
Suspended solids	12	4	7	8	2	5			
Conductivity				4	2	2	10	5	5
Period and frequency of research	Jan.78- June 78 twice a month, metals every 3 days			March 78 - Nov.78 once a month, metals 5 x a month			March 78 - Dec.78 once a month, metals: Series I March-Aug. every 2 days, Series II monthly Sept.-Dec. every 30 minutes		

These changes in nitrogen compound concentration may be an artifact of the sensitivity of the tests. The range of changes in concentration of water quality parameters is higher in all cases than the range of the accuracy of measurements; however, no trend of the changes in water quality parameter concentration is evident.

Metals

To learn more of the impact of open cooling systems on changes in cooling water chemical composition, analyses of intake and discharge water were supplemented by analyses of heavy metal concentrations at the Gdansk, Rybnik and Skawina power plants. The Water Management Division performed analyses of Fe, Zn, Cu, Pb, Ni, and Cr. Changes in the concentrations of these metals during passage through the cooling system would indicate corrosion or deposition. Changes in the chemical form of the metals from chemically bound to more toxic ionized forms could harm aquatic food chains. Tables 5a,b,c show the range of metal concentrations in the intake and discharge water in the power plants under investigation.

To determine the potential for corrosion products in the cooling water, analyses of condenser materials were conducted. Condensers in Polish power plants are constructed of 2 kinds of material: M-70 and MC-70. M-70 condensers are used in older power plants (Siekierki, Skawina, Miechowice, Gdansk). This alloy contains 69-72 per cent copper, 0.07 per cent arsenic with the remainder of zinc. MC-70 condensers are used in new power plants (Turow, Lagisza, Rybnik). MC-70 alloy consists of 69 to 71 per cent copper, 0.7 to 1.0 per cent tin, 0.02 per cent phosphorus, with the remainder of zinc.

During the research on metal concentrations in cooling water, it was expected that the main source of cooling water pollution would be corrosion. To describe the impact of corrosion processes on the changes of cooling water quality, a comparison of positive and negative differences between intake and discharge concentrations were compared for the metals under investigation (Table 6). Increase in metal content was considered a positive difference. The analysis of metal concentration changes in cooling water shows differences between facilities and metals in the frequencies of occurrence of metal increases or decreases in discharge water compared to intake water.

In the case of iron, an increase of concentration at the discharge was observed at the Gdansk and Skawina power plants and a decrease in the case of the Series II at the Skawina power plant. For copper analyses in all power plants under investigation, there was a consistent increase of concentration at the discharge compared to the intake. Like copper, increases of zinc content through the cooling system were observed for almost all power plants under investigation. Lead content in cooling water was observed to change slightly due to passing through the cooling installations. In the case of chromium and nickel for both plants under investigation (Gdansk and Rybnik), an increase of concentrations of these metals in discharge water in comparison to intake water were observed.

Statistical Analysis

As shown by the results of the analyses, there is little consistency in the relationships developed for the various metals. Because of this, additional statistical analyses of the acquired data were conducted. Student's t test was applied, since less than 120 data points were acquired. For the probability level $\alpha = 0.9$, differences between values of metals concentrations at the intake and discharge were shown not to be statistically important. Apparent

Table 5a. Range of metals concentration changes observed at the Gdansk Power Plant Cooling Water

Metal	No. of samples	Range of concentration at the intake	Range of concentration at the discharge
Iron	56	0.15-1.5	0.1-3.5
Zinc	37	0.0-0.1	0.005-0.15
Copper	56	0.0-0.05	0.002-0.06
Chromium	54	0.001-0.014	0.003-0.016
Nickel	44	0.0-0.006	0.001-0.006

Table 5b. Range of metals concentration changes observed at the Rybnik Power Plant Cooling Water

Metal	No. of samples	Range of concentration at the intake	Range of concentration at the discharge
Zinc	36	0.04-0.2	0.04-0.2
Copper	39	0.008-0.035	0.01-0.04
Lead	40	0.001-0.014	0.001-0.019
Chromium	31	0.0005-0.005	0.0005-0.005
Nickel	41	0.003-0.011	0.005-0.013

Table 5c. Range of metals concentration changes observed at the Skawina Power Plant Cooling Water

Metal mg/l	No. of samples	Range of concentration at the intake	Range of concentration at the discharge
		Series I	
Iron	92	0.17-1.8	0.21-2.3
Zinc	88	0.08-0.72	0.08-0.97
Copper	77	0.001-0.016	0.0-0.016
Lead	80	0.007-0.07	0.0-0.08
		Series II	
Iron	96	0.7-2.1	0.7-2.2
Zinc	94	0.1-0.8	0.1-0.9
Copper	87	0.002-0.015	0.001-0.017
Lead	94	0.006-0.06	0.007-0.06

Table 6. Comparison of metals concentration changes between the intake and discharge

Power Plant	Gdansk			Rybnik			Skawina					
							series I			series II		
Metal	No. of samp.	Change		No. of samp.	Change		No. of samp.	Change		No. of samp.	Change	
		+	-		+	-		+	-		+	-
Iron	56	43	12	-	-	-	92	46	39	96	35	54
Zinc	37	34	3	36	24	10	88	38	40	94	48	39
Copper	56	43	8	39	31	7	77	45	6	87	55	18
Lead	-	-	-	40	12	25	80	31	28	94	41	43
Chromium	54	46	4	31	14	10	-	-	-	-	-	-
Nickel	44	33	2	41	25	14	-	-	-	-	-	-

differences between means for the short research series should be considered to result in large part from sampling or analytical error.

Summarizing the results of our research in power plants with open cooling systems, one may say that no significant changes of basic parameters of cooling water quality during permanent power plant operation have been determined. The chemical quality of water discharged from open cooling systems depends on the chemical quality of intake water. However, during cooling system cleaning, it is expected that an increase of metal concentrations in water discharged from the cooling system will occur.

Thus, the operation of open cooling systems has an effect on concentrations of pollutants in cooling water which is too low to be observed given the large values of water involved. The results tend to confirm the opinion normally held that open cycle cooling systems contribute only trace amounts of metals to the environment.

2.2 Impact of Closed Cooling Systems on Surface Water Quality

2.2.1. Discussion of Field Research Results

Studies to describe the impact of closed cooling systems on surface water quality have been carried out by the Krakow and Gdansk Divisions of the Institute of Meteorology and Water Management for the following power plants: Turow, Lagisza, Laziska, and Miechowice. Analyses were made of wastewatewater management for these plants. The water supply system for each cooling system is discussed below as well as the mass balance for pollutants discharged from the plants.

Research at the Turow power plant was carried out in 1975 and 1977 by the Institute's Division in Wroclaw (Ref. 19, 20). The plant has an installed capacity of 2000 MW and uses lignite. Make-up water is drawn primarily from the Witka River. Periodically, part of the make-up water is taken from the Nysa Luzycka River as indicated in Table 7. The cooling system consists of 9 cooling towers with a flow rate of 27,000 m^3/h each with a cooling range of 9 degrees C. Research on water quality changes in the cooling system was carried out from October to December, 1977. Analyses of mean daily samples of cooling water were made. Results are presented in Table 8. Comparison of make-up water drawn from the Witka River and the Nysa Luzycka River with water discharged from the cooling towers shows that an increase of pollutant concentrations in the discharge is mainly due to evaporation. In the case of nitrates, a significant increase of concentration is observed as a partial result of the large decrease of nitrite content. This indicates a high intensity of nitrification. Water discharged from cooling towers contains several times more sulphur and sulphates. Also, the concentrations of TDS-TSS in water discharged from the cooling system is significantly higher than in the make-up water.

The Krakow Division of the Institute of Meteorology and Water Management carried out a series of water and wastewater measurements in the Laziska power plant. This power plant, originally constructed in 1918, had an installed capacity of 1230 MW after reconstruction in 1973. The closed cooling system of the power plant is equipped with 12 cooling towers of an approximate hydraulic output of 4,000, 6,000, 4 x 8,000, 2 x 17,000 and 4 x 30,000 m^3/h.

Table 7. Proportion of intake water from the Nysa Lużycka in the period of field studies

Period of field studies	Total make - up water m^3/ day	Intake water from the Nysa Lużycka %
Oct. 26/27	105 954	17.6
Oct. 27/28	100 053	7.2
Nov. 16/17	95 940	1.3
Nov. 17/18	99 360	0.0
Nov. 29/30	68 622	6.1
Nov. 30/Dec. 1	93 423	9.5

Table 8. Results of cooling water chemical analyses performed from October to December, 1977 at the Turow power plant

Indicator		Witka Intake	Nysa Intake	Water in cooling cycle
Water flow	m^3/day	87.180	8054.4	8.06
Reaction	pH	7.22	7.64	8.06
Alkalinity	mval/l	0.53	1.82	2.32
Hardness	^{o}n	5.05	7.80	20.73
COD	mgO_2/l	39.6	39.52	48.40
Ammonia	mg/l	0.152	2.140	0.350
Nitrate	"	2.363	2.224	10.295
Nitrite	"	0.110	0.330	0.020
Organic nitrogen	"	0.658	1.122	1.290
Phosphorus	"	0.0433	0.5306	0.400
Total Sulphur	"	53.12	85.76	234.68
Sulphates	"	51.85	84.12	227.95
Chlorides	"	19.15	41.4	64.0
Silica	"	14.28	16.38	56.75
Iron	μg/l	346.7	814.0	470.8
Copper	μg/l	12.8	15.8	21.2
Zinc	μg/l	60.5	65.6	60.0
Chromium	μg/l	2.0	6.2	11.0
Mercury	μg/l	3.80	0.44	1.68
Lead	μmg/l	28.0	29.2	29.8
Nickel	μmg/l	33.0	28.8	55.3
Dry residue	mg/l	213.7	380.4	794.5
Total dissolved solids	mg/l	197.3	327.6	762.5
Total suspended solids	mg/l	16.3	52.8	32

more sulphur and sulphates. Also the concentrations of TDS-TSS in water discharged from the cooling system increases significantly as compared to its amount in the make-up water.

Table 9. Results of analyses of cooling water made on June 4,1975 at the Laziska Power Plant

Parameter	Intake	Blowdown	Concentration coefficient
Reaction pH	8.1	8.7	-
BOD_5 mgO_2/l	3.8	2.4	-
COD mgO_2/l	29.6	11.0	-
Alkalinity mval/l	1.9	2.7	-
Hardness "	9.75	14.6	1.50
Calcium mg/l	101.5	144.3	1.42
Magnesium "	65.5	89.7	1.50
Sodium "	100.0	175.0	1.75
Potasium "	8.5	-	-
Silica "	8.0	14.0	1.75
Iron "	0.05	1.5	-
Manganese "	1.54	0.0	-
Copper "	0.007	0.002	0.20
Zinc "	0.074	0.034	0.46
Lead "	0.002	0.004	2.00
Nickel "	0.0	0.0	-
Mercury "	0.0	0.0	-
Arsenic "	0.0045	0.0065	1.44
Chromium "	0.0	0.0	-
Cobalt "	0.012	0.016	1.33
Cadmium "	0.0031	0.004	1.20
Vanadium "	0.032	0.038	1.10
Chlorides "	36.9	124,0	3.36
Sulphates "	100.1	1038.0	2.54
Phosphates "	0.0	0.165	-
Ammonia "	0.0	0.0	-
Nitrite "	0.0	0.0	-
Nitrate "	0.081	0.036	0.44
Organic nitrogen "	0.85	2.79	3.28
Phenols "	0.016	0.002	0.12
Cyanides "	0.004	0.0013	0.32
Dry residue "	810.0	2050.0	2.53
Dissolved solids "	810.0	2032.0	2.51
Suspended solids "	0.0	18.0	-

To supply water lost from the power plant cooling system, decarbonized mine water is used. Usage of make-up water for the cooling system ranges from 2,200 to 2,250 m^3/h. Measurement of make-up water carried out on June 4, 1975 included the analyses of the chemical composition of mine water added to the cooling system and water discharged from cooling towers. Results of the analyses are presented in Table 9.

Mine water contains quite a lot of salt with sulphates and chlorides in the largest concentrations. Blowdown water discharged from the cooling towers contains concentrations of sulphates and chlorides which are three times higher due to evaporation. Relatively higher concentration of organic nitrogen are observed which could be a result of microorganisms present in the cooling water. Attention should be given to zinc and copper concentration decreases. This phenomenon has not yet been explained.

To investigate the changes of water quality during its passage through the cooling system, field research was carried out for the Turow, Drzymala, and Lagisza power plants by the Institute of Environmental Engineering at Wroclaw Technical University during the period from August, 1978 to April, 1979. The characteristics of the Turow power plant in Bogatynia and its water management were presented above. The Drzymala power plant in Miechowice and the Lagisza power plant use lignite. The amount of sulphur in the lignite used in the Drzymala power plant in Miechowice is about 0.9 per cent, and in the Lagisza power plant it ranges from 1 to 1.5 per cent. The Miechowice power plant of 220 MW installed capacity (4 units of 55 MW each) is supplied with make-up water from municipal sources. Preliminary preparation of water is made before it gets to the cooling system. Twenty five percent of the water is decarbonized with lime in a settling basin and passed through mechanical filters. Seventy five percent of the water is neutralized with hydrochloric acid and the addition of blowdown water containing phosphate from boilers. The closed cooling system of the Miechowice power plant is equipped with 4 wooden cooling towers.

The Lagisza power plant (7 units of 120 MW each) is supplied with make-up water from the Czarna Przemsza intake in the amount of 27,000 m^3 per day. The make-up water for the cooling system is prepared by decarbonization with lime and coagulation with ferrous sulphate - $FeSO_4$. The closed cooling system of the Lagisza power plant is equipped with 6 hyperbolic reinforced concrete cooling towers.

In the three power plants under investigation, water samples were taken once a day during 3 consecutive days of each month (27 samples). Analyses were made for make-up water and for water circulating in the cooling system. Results of the cooling water analyses are presented in Table 10. For each indicator of water quality presented in Table 10, a mean concentration coefficient (ratio of particular compound content in circulating water to its content in make-up water) was calculated, representing the degree of concentration of make-up compounds in the closed cooling systems. In all cooling systems under investigation, concentration coefficients calculated for heavy metals differ significantly from concentration coefficients calculated for other indicators. The biggest differences were observed in the Turow power plant for mercury (calculated concentration coefficients for chlorides - 1.3, for mercury - 2.4). Smaller, but significant differences are also noticed for iron, zinc, lead, molybdenum in the Turow power plant, for nickel in the Miechowice and Lagisza power plants, for manganese in all power plants, and for mercury in the Miechowice power plant.

Table 10. Results of cooling water chemical analyses carried out by the Water Management Division of IMWM at the Turow, Miechowice and Lagisza power plants

Indicator	Turow			Miechowice			Lagisza		
	Make-up water	Cooling water	Calcul. concentr. coeff.	Make-up water	Cooling water	Calcul. concentr. coeff.	Make-up water	Cooling water	Calcul. concentr. coeff.
Reaction pH	7.6	7.3	-	7.2	7.1	-	7.5	7.4	-
Alkalinity mval/l	1.96	1.89	-	1.89	1.89	-	2.06	1.97	-
Hardness germ. deg.	39.18	34.60	0.83	56.83	59.4	1.05	60.0	54.35	0.91
Calcium mg/l	68.9	81.0	1.2	134.8	148.7	1.1	141.6	169.1	1.2
Magnesium "	23.5	25.7	1.1	29.6	36.1	1.2	26.4	34.6	1.4
Sodium "	79.1	93.5	1.2	71.9	86.1	1.2	55.9	71.0	1.3
Potasium "	14.0	15.4	1.1	13.7	16.9	1.2	14.8	17.4	1.2
Ammonia "	0.043	0.044	1.02	0.30	0.033	1.1	0.038	0.042	1.1
Nitrite "	0.0138	0.0144	1.04	0.0167	0.0184	1.1	0.0193	0.0202	1.05
Nitrate "	6.12	8.5	1.4	5.63	7.0	1.2	3.19	3.71	1.2
Sulphates"	2003	235.6	1.2	262.7	348.9	1.3	248.1	310.0	1.2
Chlorides"	66.1	85.7	1.3	80.9	111.9	1.4	79.4	87.5	1.1
Iron "	0.408	0.651	1.6	0.375	0.493	1.3	0.483	0.565	1.2
Zinc "	0.039	0.066	1.7	0.031	0.040	1.3	0.038	0.050	1.3
Copper "	0.011	0.017	1.5	0.017	0.024	1.4	0.020	0.028	1.4
Lead "	0.014	0.025	1.8	0.021	0.030	1.4	0.030	0.039	1.3
Nickel "	0.008	0.012	1.4	0.014	0.021	1.5	0.018	0.028	1.6
Manganese"	0.051	0.090	1.7	0.046	0.070	1.5	0.041	0.061	1.5
Mercury "	0.0	0.0	2.4	0.0	0.0	1.5	0.0	0.0	1.4
Molybdebum"	0.004	0.008	1.9	0.011	0.015	1.3	0.016	0.021	1.3
Dissolved solids "	787.8	756.6	0.96	874.3	862.0	0.99	854.9	820.1	0.96
Suspended solids "	153.1	136.9	0.90	255.4	260.0	1.02	169.6	165.2	0.97

The higher concentration coefficient for heavy metals is not only a result of evaporation but also suggests the possibility of the contribution of metals from other pollution sources, e.g. corrosion and wash out by water from the air in cooling towers. The issue of wash out of pollutants by water from the air in cooling towers is discussed in the next section of this report.

Differences of the concentration coefficients of various forms of nitrogen may indicate intensive nitrification. In the cooling waters of the investigated closed systems, the concentration coefficient of nitrites is higher than the concentration coefficients for ammonia and nitrites. Concentration coefficients equal to or less than 1 for dissolved and suspended substances are the result of precipitation in the cooling tower basin.

2.2.2 Evaluation of the Pollutant Load Washed Out of the Air

The load of pollutants washed from the air can be defined by the following dependency:

$$U = Q \lambda_o \mu \cdot X_p$$

where:

- U - the load of pollutants washed from the air mg/s
- Q - cooling system flow rate (m^3/s)
- λ_o - volumetric ventilation coefficient, volume of air passing through the cooling tower /m^3 of circulating water. On the basis of theoretical work by the Polish Energy Institute (13), it was calculated that the average value of the coefficient is equal to 430 m^3 of air per m^3 of circulating water
- μ - rate of wash out from the air (%)
- X_p - Concentration of pollutants in the air entering the cooling tower (mg/m^3)

Wash out of pollutants from the air is a relatively new problem which has not been analyzed previously with respect to cooling towers. The following are the first Polish results as carried out by the Institute of Environmental Protection of the Technical University of Wroclaw. The field tests were carried out from November 1977 till April 1979 on the cooling towers of the Turow, Lagisza and Miechowice power plants.

A total of 130 measurements were made on the concentrations of pollutants in the air flowing through the cooling tower. The monitoring locations in the air were located at the inlet to the cooling tower and above the sprayers. The tests were mainly aimed at defining the wash-out of metals (iron, zinc, copper, nickel, manganese, mercury), as well as sulphur dioxide and nitric oxides. The results of the field tests are given in Tables 11 and 12. The tests performed show that an average of 20% of the examined pollutants contained in the air pass into the cooling water. Calculations show that in the cooling tower of the Turow power plant which has a daily cooling capacity of 27,000 m^3/h, the average daily loss of air pollutants to the cooling water is: 3.9 kg sulphur dioxide, 10.4 kg nitric oxides, 4.7 kg iron, 16.8 g zinc, 26.9 g copper, 33.7 g lead, 9.1 g nickel, 11 g manganese, 5.7 g mercury. At the Lagisza power plant, 6 series of detailed examinations were made to measure the change of air pollution adjacent to the cooling tower up to 4 m high and the change of pollution in water flowing from the sprayers. These tests showed that the concentrations of most pollutants in the air increase with height. This is especially true with regard

Table 11. Average values of pollutant concentrations in the air passing through the cooling tower /measured outside the cooling tower at the inlet/

Power plant	Time of sampling /hours/	Gases		Metals						
		SO_2 mg/m^3	NO_x mg/m^3	Fe mg/m^3 x 10^{-2}	Zn mg/m^3 x 10^{-4}	Cu mg/m^3 x 10^{-4}	Pb mg/m^3 x 10^{-4}	Ni mg/m^3 x 10^{-4}	Mn mg/m^3 x 10^{-4}	Hg mg/m^3 x 10^{-6}
Turow	10-13	0.102	0.449	8.48	3.02	5.05	5.88	2.68	2.22	9.9
	13-16	0.069	0.264	7.73	1.59	3.20	3.94	1.047	10.17	7.81
	16-22	0.051	0.234	6.99	1.02	2.04	2.89	0.846	8.32	7.10
	22-10	0.027	0.147	6.01	0.755	1.26	2.37	0.745	6.70	5.06
Miechowice	10-13	0.172	0.608	7.283	2.177	1.908	5.888	2.124	8.143	6.623
	13-16	0.112	0.408	6.41	1.494	1.587	5.217	1.773	6.690	5.987
	16-22	0.068	0.264	5.58	1.005	1.164	3.99	1.370	6.013	4.927
	22-10	0.046	0.208	4.60	0.811	0.962	3.20	1.196	5.43	4.908
Lagisza	10-13	0.210	0.391	7.653	2.442	1.873	6.092	2.413	8.602	6.978
	13-16	0.099	0.266	7.194	1.942	1.518	5.900	1.954	7.74	6.088
	16-22	0.084	0.160	7.050	1.707	1.457	4.712	1.787	7.802	5.343
	22-10	0.071	0.106	6.022	1.089	1.048	3.652	1.313	6.730	4.848
Laziska	10-13	0.161	0.399	8.12	2.41	2.03	6.05	2.45	8.86	7.22
	13-16	0.091	0.209	7.48	2.06	1.46	5.06	1.61	7.12	5.12
	16-22	0.086	0.166	5.96	1.41	0.961	4.52	1.18	5.28	4.82
	22-10	0.071	0.138	3.81	1.03	0.812	3.82	0.969	5.01	4.12

Table 12 . Degree of pollutants wash-out from the air by water in cooling towers of the Turow, Miechowice, Lagisza and Laziska power plants

% Reduction in Air Pollutant Concentration Above the Sprays as Compared with the Inlet

Power plant		Gases		Metals						
		SO_2	NO_x	Fe	Zn	Cu	Pb	Ni	Mn	Hg
Bogatynia	min	0.00	0.00	0.40	1.00	0.10	3.20	2.00	3.00	4.80
	mean	18.19	19.94	18.13	20.49	20.50	22.01	16.69	19.94	22.02
	max	37.50	60.80	13.00	36.00	47.00	42.00	41.00	37.00	48.00
Miechowice	min	4.00	5.10	3.00	3.50	4.20	3.90	1.60	3.60	4.00
	mean	18.67	18.07	20.24	18.70	17.67	20.53	20.70	25.40	23.11
	max	31.20	30.10	40.00	37.00	33.00	34.70	44.00	76.00	43.00
Lagisza	min	3.80	0.80	2.90	1.80	6.60	3.40	5.00	3.20	5.10
	mean	20.42	17.49	17.78	19.25	18.33	19.91	16.26	20.29	17.57
	max	37.00	31.00	30.00	31.00	31.00	30.00	27.00	35.00	30.00
Laziska	min	7.00	10.80	6.00	5.40	6.40	7.50	8.00	7.80	5.80
	mean	8.15	13.95	9.15	10.10	7.75	12.40	10.82	9.98	10.42
	max	8.80	18.80	13.70	15.60	10.30	18.30	14.40	12.60	15.60

to such metals as: Ni, Pb, Cu, Zn for which concentration grew with height in every instance. At 4 m the increase of concentration of the above metals in $mg/m^3 \times 10^{-4}$ above ground level varied within the limits: Ni: 5-11.2%, Pb: 2.6 - 11.5%, Cu: 3.7 - 8.8%, Zn: 6.0 - 18.0%. With regard to the remaining pollutants, this tendency is also indicated, although it was not as prominent in each of the series of measurements. The change in quality of water flowing from the sprayer was examined at sampling points located at 1, 3, 5 and 7 m. above the water surface in the cooling tower basin. The change of quality of water at these elevations is shown in Table 13. The results show the following increases of pollutants in water between the 7m and 1m levels: Chlorides Cl^- - 17%, total nitrogen - 11%, sulphates - 18.5%, calcium compounds - 35.2%, manganese compounds - 28.9%, phosphorus compounds - 16.2%, iron Fe 31.2%, copper Cu - 22.8%, zinc Zn - 17.6%, chromium Cr - 23.7%, mercury Hg -43.1%, Nickel Ni - 16.4%, cadmium Cd 44.0%, cobalt Co - 17.4%, vanadium V - 20.6%. In spite of the considerable increase of pollutants contained in water, flowing from the sprayer system in the cooling tower, no comparable permanent increase of such pollutants was observed in the water continuously circulating in the cooling system. Chemical laboratory tests made to clarify this process showed that most of the washed out compounds go through further transformations in the cooling water, resulting from the increase in pH of the water and resulting precipitation of residues. The contents of most of the compounds washed out from the air in the cooling water, consisting mainly of metals, are largely dependent on the reaction rate and the temperature of the water. In the conditions existing in the cooling tower basin, most of the pollutants washed out from the air are precipitated.

Table 13 . The change of quality of water at the cooling tower

Pollutants	Water flowing from the sprayer				Water in the cooling tower basin		
	Height above the water surface in the cooling tower basin /m/				deep below the water surface in the cooling tower basin /m/		
	7	5	3	1	0.0	0.7	1.5
Chlorides mg Cl^-/ l	87.8	94.8	97.0	102.7	103.7	101.8	104.2
Total nitrogen mg N/l	1.842	1.878	1.936	2.042	2.185	2.241	2.827
Sulphates mg S/l	308	326	349	365	369	356	347
Calcium compounds mg/l	79.5	88.5	97.5	107.5	109.3	109.5	114.2
Manganese compounds mg/l	40.2	43.7	45.7	51.8	53.4	50.0	48.8
Phosphorus compounds mg	0.185	0.195	0.203	0.215	0.228	0.233	0.250
Iron µg Fe/l	254	274	309	334	342	356	361
Copper µg Cu/l	27.0	28.7	30.5	33.6	34.2	37.7	40.0
Zinc µg Zn/l	41.5	43.0	45.6	48.8	50.5	59.3	60.3
Chromium µg Cr/l	2.02	2.23	2.47	2.50	2.60	2.70	2.80
Mercury µg Hg/l	0.058	0.065	0.077	0.083	0.088	0.096	0.105
Nickel µg Ni/l	31.5	33.0	34.8	36.7	37.5	39.2	40.2
Cadmium µg Cd/l	32.2	34.0	36.7	46.3	46.6	49.0	49.5
Cobalt µg Co/l	28.7	30.8	33.0	33.7	33.7	32.8	34.3
Vanadium µg V/l	16.0	17.2	17.7	19.3	20.2	20.8	22.3

3. Make-up Water Demand and Water Loss in Closed Cycle Cooling Systems

Important considerations in the evaluation of cooling systems are the seasonal variation of make-up water demand and the dependence of total make-up water demand and water loss on plant efficiency. Project JB-5-537-4 explored the following topics:

- The theoretical basis for the calculation of evaporation loss
- A comparison of theoretical values of evaporation loss with values obtained from field studies and with values presented by other authors
- An analysis of different elements of make-up water balance
- An analysis of the total water demand of steam power plants for closed cooling system use as well as for other purposes

3.1 Make-up Water Demand Analysis for Closed Cycle Cooling Systems

The amount of make-up water needed to compensate for losses in closed cycle cooling systems is defined by:

$$Q_m = Q_e + Q_d + Q_b + Q_p \qquad (1)$$

where:

Q_e = amount of water lost by evaporation
Q_d = amount of water lost by drift
Q_b = amount of water lost by blowdown
Q_p = amount of water needed by the power plant water treatment system

The separate components of the balance depend on many varying technical and natural factors.

3.2 Evaporation Losses in Cooling Towers

The calculation of evaporation losses assume that the whole volume of air going up through the cooling towers will be saturated with water vapor. Zembaty and Radwanski (1978), on the basis of the theoretical calculations, report that the share of evaporation in total heat loss amounts to:

- up to 38% for very low temperature
- up to 62% in January
- up to 70% in October and April
- up to 81% in July

Utilizing the theoretical basis presented by Zembaty and Radwanski (1978), an additional calculation of the change of evaporation losses has been made as a function of the following parameters:

- heat discharge load of cooling tower: $A = Q \cdot \Delta t$ (Kcal/s)
- surface of horizontal cross-section of spray system: F (m^2)
- effective height of the cooling tower H_e (m)

Calculations were made for the following assumed cooling system specifications:

- air temperature t_a = 15°C
- relative humidity of air: ϕ = 70%
- cooling water flow: Q = 8000 l/s
- temperature rise through the condenser t = 8.35°C

The results of calculations given in Table 1 show that the fraction of heat lost through evaporation depends on the heat load of the cooling tower and on atmospheric conditions. Atmospheric conditions determine the share of total heat lost during the evaporation of water. Under the assumed atmospheric conditions, the coefficients defining the share of heat lost by evaporation amounts to approximately 72% and does not depend on changes of other parameters. This value corresponds with the results of research performed in the Neurath C Power Plant (Baer et al. 1974, 1979) which are discussed later in this report.

Table 14

Evaporation Losses in a Cooling Tower Depending on the Heat Load Sprayer Surface and the Cooling Tower Height

Coefficients of change of basic quantities	Surface of the Sprayer F_z (m^2)	Effective height of the cooling tower H_e (m)	Heat load of cooling tower (A) Kcal/s	Q_e kg/s	Fraction of heat lost during evaporation
Q = 1.0	4,415	100	75,000	93.6	72.5
Q = 0.75	4,415	100	56,250	69.5	71.7
Q = 0.5	4,415	100	37,500	45.8	70.9
F_z= 1.25	5,500	100	75,000	92.2	71.4
F_z= 1.0	4,415	100	75,000	93.5	72.3
F_z= 0.75	3,300	100	75,000	93.7	72.5
He= 2.0	4,415	200	75,000	93.7	72.5
He= 1.5	4,415	150	75,000	93.7	72.5
He= 1.0	4,415	100	75,000	93.5	72.5
He= 0.5	4,415	50	75,000	94.1	72.6

The results of theoretical calculations were compared with the results of a one year field study of water balance in the closed cooling system of Power plant No. 7 (see Table 15) which was the subject of detailed analysis. Plant No. 7 consists of four generating units of approximately 55 MW capacity each, giving a total capacity of 220 MW. The cooling system consists of 4 steel structure natural draft cooling towers with asbestos fill, each receiving a 10,000 m^3/h water load. The cross sectional surface of each cooling tower base is 1,256 m^2 and that of the spray system is 1,190 m^2. The height of the cooling towers is H = 45 m, and height of the spray system is H_z = 5.0 m; the air inlet is at H_0 = 2.8 m. City water is supplied to the cooling system. As noted in Table 2, some of the make-up water is decarbonized with lime and neutralized with hydrochloric acid. The concentration coefficient K is on the order of 6.

The daily water consumption of the power plant was measured on a water-meter while the quantity of water for cooling purposes was established from the changes of water level in the cooling tower basin and changes of water

Table 15

Balance of daily water demand for the cooling system in Steam Power Plant No 7 (Oct 1976 - Sept 1977)

Data	Power Plant Make-up Water m^3			Cooling System Balance m^3				Heat discharge to the cooling system G cal	Electric energy product. MWh	Coefficient of evaporation losses	
	fresh water	decarbonized	total	blow-down	sludge discharge	drift	evaporation			m^3/MWh	m^3/Gcal
1	2	3	4	5	6	7	8	9	10	11	12
Oct	92,371	77,656	170,027	1304	2702	12,484	153,537	109,235	59,238	2.59	1.40
Nov	117,435	75,280	192,280	1259	1276	16,563	173,617	137,473	76,374	2.27	1.26
Dec	141,420	76,152	217,572	1025	2800	18,737	196,010	154,766	85,981	2.28	1.27
Jan	167,902	78,148	246,050	1392	6006	21,308	217,350	188,042	101,262	2.15	1.16
Feb	129,042	138,981	268,023	1008	1554	22,616	242,845	193,366	104,128	2.33	1.26
Mar	158,932	106,548	265,480	1146	2600	13,344	239,390	187,135	100,773	2.38	1.28
Apr	209,600	62,680	272,280	1050	900	24,141	246,180	190,712	102,699	2.40	1.29
May	252,907	62,275	316,182	1134	21,300	25,339	268,409	195,113	105,069	2.55	1.38
Jun	253,463	42,675	296,138	1195	34,000	20,193	240,750	176,603	88,212	2.73	1.44
July	291,818	-	291,818	1131	52,500	19,575	217,612	156,602	82,422	2.64	1.39
Aug	280,698	-	280,698	1066	25,500	19,895	224,237	165,125	86,908	2.58	1.36
Sept	242,615	33,559	276,174	1053	16,600	29,981	237,540	174,145	91,655	2.59	1.36

level in the cooling water channel. The quantity of blowdown water discharged was measured with a sampling bucket and stop watch.

The water demand data for the cooling system are given in Table 15 for the period under investigation (October 1976 - November 1977). Since there was no way to measure the drift, its value was assumed at 0.1 percent Q since drift eliminators were not present; the amount of evaporative loss as a percentage of the total make-up water, (column 8) divided by (column 4) in Table 15 ranges from approximately 75 to 90% with an average of 86%. From May to August, the percentage is lower than during the remaining months of the year. The amount of heat discharged due to evaporation as compared with the total heat discharge of the cooling system is approximately 68 to 83% and during the period under investigation its average is approximately 77%. From May to October, the percentage is slightly higher than during the remaining months of the year. The steam power plant make-up water balance is characterized by the following proportions:

- evaporation 85.9%
- drift 7.9%
- blowdown 6.2%

The foregoing calculations can be partly compared with the results of unique measurements made at the 300 MW Neurath C Power Plant, Federal Republic Germany for a cooling tower of 100 m height and 74.5 m diameter at the base. The cooling cycle parameters are as follows:

- Q - cooling water flow = 29,600 m3/h
- Δt - temperature rise through the condenser = 12.6° C
- C_k - power plant discharge of heat, 1243 Kcal/kWh
- temperature of hot water discharge - 34.2° C
- temperature of intake water - 21.6° C
- temperature of air - 9.5° C
- wet - bulb temperature - 7.6° C
- air relative humidity - 77%
- design drift - 0.054% Q
- design evaporation losses - 1.61% Q = 1.59 l/kWh
  which equals 68.6% of the total heat loss

Studies by numerous specialists from many countries were carried out from July 1973 till July 1976. 187 series of measurements were made covering all seasons of the year, as shown in Table 16 below.

Cooling Tower Studies at Neurath C Steam Power Plant

Year	Season of the Year	Study Period	Number of Series of Measurements
1973	Summer	July 18 to July 22	14
1973	Autumn	Sept. 28 to Oct. 6	28
1973	Winter	Dec. 14 to Dec. 16	29
1974	Summer	June 25 to Aug. 25	20
1975	Winter	Feb. 7	26
1975	Summer	June 17 to June 20	11
1976	Winter	Feb. 1 to Feb. 5	9
1976	Summer	July 2 to July 6	50
			187

The site measurements included:

- cooling water flow
- water temperature
- climatic conditions
- thermodynamic state of cooling tower plume
- distribution of droplet size
- speed and direction of wind up to 1600 m altitude

The results of research were presented in the papers of Baer et al. (1974, 1979) and Dittrich and Ernst (1980). Utilizing the above papers, the portion of evaporative heat loss was calculated. The values obtained are given in Figures 16 and 17. The calculations show that the proportion of evaporative heat loss varies within a wide range depending on climatic conditions, particularly temperature and humidity of the ambient air.

In winter when the air is cool and humid, the portion of evaporative heat loss amounts to approximately 50% while in the summer, when the weather is hot and dry, it can reach 90%. The average heat exchange due to evaporation amounts to approximately 72.9% at a mean air temperature of 14 degrees C. Through a least squares analysis the average portion of evaporative heat loss was shown to be expressed as:

$$A_c = 60 + 0.833\, t_a (\%) \qquad (2)$$

where:

A_c = share of evaporation in the process of heat exchange
t_a = air temperature, degrees C.

Evaporation losses, as a percentage of total cooling water flow, as normalized to t = 10 degrees C are shown in Figure 17. The losses change within the range of 0.9 to 1.7% Q. The average value of evaporation losses for the Neurath Steam Power Plant for t = 11.44 C amounted to 1.565% Q. An estimate of cooling water evaporation losses in percent of cool water demand is:

$$Qe = (0.11 + 0.00156\, t_a)\ t \qquad (3)$$

where:

Q_e - evaporation losses in percentage of cooling water demand
t_a - temperature of air ^{o}C
t - heating in condenser ^{o}C

A comparison of the field study results obtained at Steam Power Plant No. 7 and Neurath C show that the results obtained are very close. The difference between the estimates of the portion of evaporative heat loss obtained by different methods, was within 3%.

Several additional studies of cooling system evaporative water loss have been reported. A summary of some of these studies is presented below.

Berman (1957) presented the relationship between evaporative water loss and air temperature as:

$$Q_e = K_1 \Delta t \cdot Q \qquad (4)$$

where:

K_1 - the coefficient of evaporation loss, which according to Berman, is equal to:

air temperature °C	-10.0	0	10.0	20.0	30.0
coefficient K_1	0.070	0.096	0.117	0.138	0.160

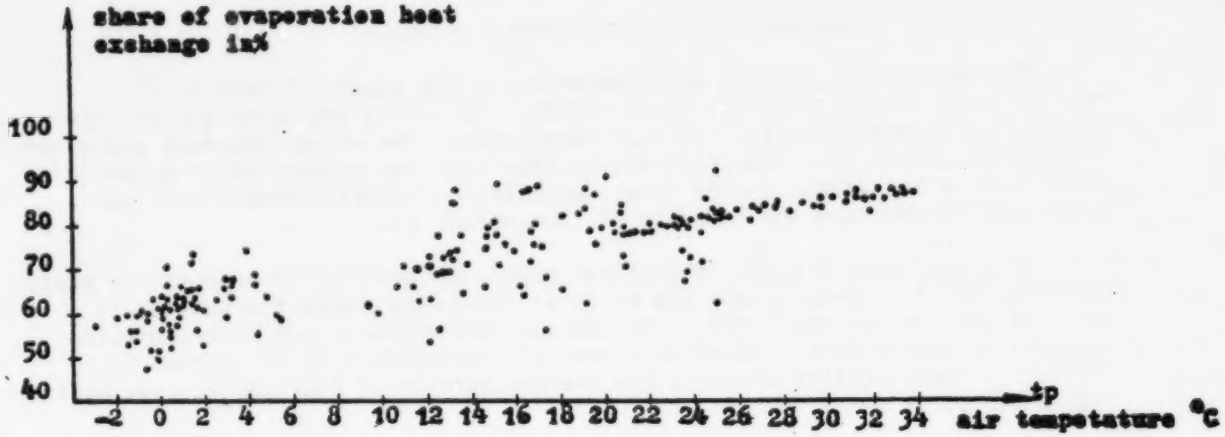


Fig. 16 Share of evaporative heat exchange in closed cooling systems based on site /Baer et al 1974, 1979/

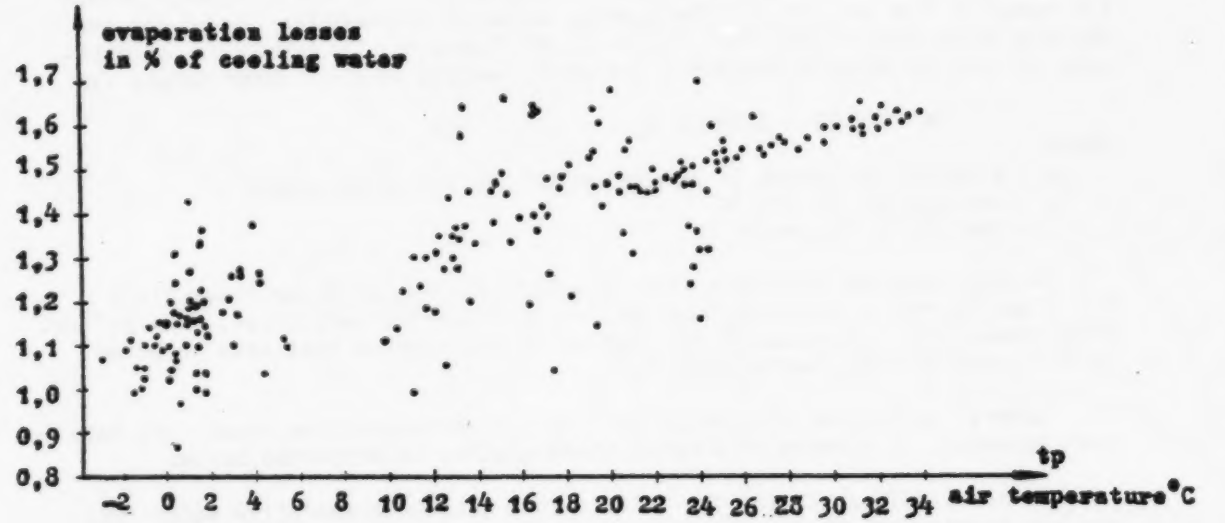


Fig. 17 Evaporation losses in closed cooling systems in % of cooling water flow assuming a Δt of 10°C, based on site /Baer et al 1974, 1979/

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This dependency can also be presented by the following formula:

$$Qe = (0.096 + 0.00213\ ta)\ \Delta\ t\ Q\ /100 \quad (5)$$

where:

t_a = air temperature, °C

In later publications, a detailed analysis of the amount of evaporation losses in a closed cooling system was also presented by Ortner (1973), who related his calculations to the Rhineland region (GFR). To define the amount of evaporation losses, Ortner applied Merkel's equation from 1921 (VIK 1970):

$$Qe = \frac{C_k\ \epsilon}{\Delta 1\ /\Delta x}$$

where:

Qe - evaporation losses (1/kWh)

C_k - heat discharged to the cooling system, assuming C_k = 1200 Kcal/kWh

$\Delta 1$ - change of enthalpy of air between the inlet and outlet from the cooling tower (Kcal/kg)

Δx - change in content of water vapor in the air between the outlet and inlet to the cooling tower (kg/kg)

ϵ - coefficient compensating for change of heat balance as a result of evaporation $\sim$ = 1 (unit loss).

The monthly amounts of evaporation loss are presented in Table 17. Calculations show that the average annual evaporation losses amount to 1.36 1/KWh.

Further calculations (Andres, Ortner, Schiffers, 1974) show that evaporation losses in conventional power plants amount to 1.38 1/kWh with nuclear power plants having an increased amount of heat discharged in the cooling system of up to 1720 Kcal/kWh and evaporative loss of 1.98 1/kWh. The following increase of evaporation losses at higher air temperature was noted (Ortner, Ritter, 1976):

Atmosph. Cond.	Temp. of air °C	Hum. of air%	Increase in evap. loss. %
Annual average	8.9	80.4	-
Summer	11.1	76.0	1.17
Hot period	34.0	57.0	40.0

According to Heine and Weidlich, the values in Table 17 show that evaporation losses are over 10% higher than those given by Ortner, while the seasonal changes for these values are smaller.

EdF (1975) gives values of evaporation losses for nuclear plants. This paper points out that for closed cooling systems with natural draft cooling towers the share of heat discharged by evaporation varies within 60 to 70%, though in some cases it can reach even 90%. Evaporation losses in France were determined to be on average basis 1.980 1/kWh (Table 17). It was also stated that under extreme conditions of 35°C air temperature and 30% humidity, evaporation losses can rise to 2.88 1/kWh, 45% higher than the annual average.

Table 17

Evaporation losses in closed cooling systems according to other authors

Author, reference region, Subject matter	Months												Annual average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Ortner /1973/, Rhineland region GFR Evaporation losses l/kWh	1.14	1.15	1.23	1.34	1.48	1.60	1.61	1.59	1.47	1.32	1.21	1.15	1.36
Ortner /1973/, Rhineland region GFR Portion of heat exchange due to evaporative losses %	51.3	51.7	55.3	6o.3	66.6	72.0	72.4	71.5	66.1	59.4	54.4	51.7	61.1
Heine, Weidlich /1974/ region GDR Evaporation losses for power plants using saturated steam l/kWh	2.09	2.12	2.23	2.30	2.48	2.48	2.52	2.52	2.45	2.34	2.20	2.09	2.32
Heine, Weidlich /1974/ region GDR Evaporation losses for power plants using superheated steam l/kWh	1.37	1.40	1.44	1.51	1.62	1.62	1.66	1.66	1.58	1.51	1.44	1.37	1.52
EdF /1975/ Evaporation losses for nuclear power plants l /KWh	1.73	1.80	1.87	1.98	2.09	2.16	2.23	2.15	2.12	2.02	1.91	1.73	1.98

For Poland, annual average losses (1/kWh) are presented below:

Author	Open System	Closed System	Pond System
Gadkowski (1971)	0.68	1.47	0.85
Spoz (1979)	0.85	2.04	0.97

Using the theoretical calculations and the results of field studies made in Poland and in the GFR, it can be stated that the portion of heat exchange due to evaporation depends on meteorological conditions and mainly on the air temperature. This dependence can be taken approximately as a linear relationship. In the average Polish climatic condition, the share of heat exchange due to evaporation losses is approximately 77%. In the case of a conventional modern steam power plant with heat discharge to cooling system C_k of approximately 1200 Kcal/kWh, this results in evaporation losses of 1.714 l/kWh. This value is higher than the values given by other authors. In earlier papers, only values given by Berman (1957) are very close to the measured values.

3.3 Drift - Q_d

Experimental research on drift values for natural draft cooling towers was initiated recently. Early literature only estimated this factor. In addition, the values of drift changed considerably as soon as cooling towers were equipped with drift eliminators. Heller, in his earlier papers (1953), values the drift at 0.2 to 0.7% Q. Freier (1963) reports these values at 0.1 to 0.3% Q. More recently, the BBC in design of a cooling tower for a 600 MW lignite fired unit, presents drift at 0.054% Q, and the Balcke Company at the VGB (Kraftwerke and Umwelt - Essen) in 1973 conference, gives a figure of 0.01 to 0.03% Q. Electricite de France (1975) estimated drift at 0.005% Q and states that with regard to nuclear power plants of 1 GW, the drift amounts to 2 l/s. Heine and Weidlich (1974) give different drift values in particular months and at various water vapor parameters (Table 18).

Table 18

Drift Value in M^3/s for a 1 GW Steam Power Plant
According to Heine and Weidlich (1974)

Kind of Power Plant	Jan.	Feb.	Mar.	Apr.	M to S	Oct.	Nov.	Dec.	Annual Average
Using saturated water vapor	0.07	0.07	0.07	0.07	0.08	0.07	0.06	0.07	0.073
Using superheated water vapor	0.04	0.03	0.05	0.05	0.05	0.05	0.04	0.04	0.045

Dittrich and Ernst (1980) evaluated the earlier results of an investigation of the terrain beside the cooling tower of the Neurath C Power Plant.

They reported that drift depends on the construction of the cooling tower and the kind of eliminators and conclude that it is difficult to make a general drift loss estimate. In connection with the above, they have presented results of research on the contents of droplets in the plume leaving the cooling tower. Both the drift and vapor condensation have an impact on the contents of the droplets.

As stated by Dittrich and Ernst (1980), the droplet content increases from about 0.2 g/kg of air to about 1.5 g/kg. The droplet content rises with rising ambient humidity and decreases with rising ambient temperature. The largest portion of water droplets form in the plume as a result of condensation. The diameter of such droplets is less than 10 m. Only a small portion of the droplets in the plume are entrained by the air flowing through the cooling tower. The diameter of these droplets is approximately 100 m. The rate at which water droplets are entrained by the air flow is 2 kg/s which equals approximately 0.0244% Q. In research conducted for this project, an attempt was made to define the region subjected to the activity of the cooling tower through examinations of rainfall, of the soil and of vegetation growing in the region. The research was conducted near the Lagisza power plant by a team from the University School of Wroclaw, supervised by J. Pacyna. Examination of rainfall was made at 12 locations over a period of 6 months from December 1979 till May 1980. The soil was examined twice at 3 locations. The results show that the cooling towers cause an increase of rainfall along a strip of about 2 km windward. Approximately 500 m from the cooling tower, an increase of almost 30% of rainfall was observed, and within 1300 m, rainfall increase amounted to nearly 10%.

In the case of the Lagisza power plant, the area of increased rainfall covers a part of the power plant such as: coal storage, slag storage, warehouses, railway tracks and water tanks. Rainfall in the region surrounding the cooling tower shows an increase of concentration of pollutants such as dissolved solids, sulphides, potassium chloride and sodium. The observed increase of the average concentration amounted to: sulphides 2.6 times, chlorides 3.0 times, calcium 3.6 times, magnesium 3.3 times. The authors of this research state that this increase indicates the intensive absorption in the cooling tower plume of pollutants contained in the air. These studies did not indicate any significant impact of the cooling tower on the changes of concentration of chemical compounds in the soil and growing plants.

3.4 Make-up Water to the Closed Cooling System

The amount of make-up water can be expressed by the following:

$$Q_m = \frac{K}{K - 1} \left[Q_e \left(1 + \frac{L}{S_a}\right) \right] + Q_d + Q_p \qquad (7)$$

where:

K - cycles of concentration; a dimensionless number which expresses the number of times the concentration of any constituent is multiplied from its original value in the make-up water

L - load of pollutants introduced to the cooling water as a result of treatment of make-up water or washed out from the air (mg/l)

S_a - admissible concentration of pollutants in cooling water

The importance of the component L/Sa should be evaluated individually e.g., reducing the carbonate hardness of make-up water from 6° to 1 to 2°; by using sulphuric acid one obtains an increase of sulphates in make-up water of approximately 80 mg/1 (1° of hardness = 10 mg/1 CaO (1). At an admissible value for sulphate concentration of 500 mg/1, the expression L/Sa can constitute about 15% of of Q_e. The component L/Sa amounts to nearly 10% of Q_e for hydrochloric acid neutralization.

3.4.1 Water Treatment Plant Make-up Water Demand Q_p

At the Polish steam power plants discussed in this report, Qp (water for treatment) amounts to 3.5 to 4.5% of makeup water needs (Qm). Water station Qp demands are rarely analyzed in the literature. This problem was discussed by Ortner (1973), who reports Q_p values for several power plants. In Power Plant B these demands amount to 5 to 6% of the make-up water, in Power Plant C, 6 to 8% of the make-up water. Detailed studies carried out in the E Power plant from June 1966 till December 1968 have shown Q_p to be 0.8 to 1.25% of the make-up water. For the case K = 4, the equation indicates Q_4 to be 0.019 to 0.035 1/kWh. Analogous research carried out in the F Power Plant from November 1969 till the end of 1971 has shown the following Q_p values as a proportion of the make-up water:

- average for the year 1971 - 1.8%
- median value from November 1964 till June 1970 - 1.25%
- highest daily values from November 1964 till June 1970 (noted approximately twice a month) 3.3 to 6.6%
- average elementary Q_p demand - 0.05 1/kWh

3.4.2 The Analysis of Demand for Make-up Water in Electric Power Plants with Closed Cooling Systems

As part of the research carried out for this project, water demand was examined in 12 power plants, the specifications of which are presented in Appendix A.

The range of concentration of various pollutants in cooling water in these plants results in a variation in K of between 2 and 10, whereas the discharge of heat to the cooling cycle varies from 1160 to 3300 Kcal/kWh. The ranges of variation of water demand indices, shown in Tables 19 to 21 and in Figures 18, 19 and 20 point out the lack of close relationship between the unit water consumption coefficients and the water concentrations coefficient K. Instead, there is a clear relationship between the water consumption indices and the unit heat discharge to the cooling system (Fig. 18). The higher the unit heat discharge, the higher is the unit water consumption, assuming similar water management systems. The annual and monthly average indices of make-up water consumption per unit of heat discharged to the cooling system (Table 21) range within much narrower limits than the indices per unit of electric energy production (Table 20).

The results obtained in Project JB-5-537-4 were compared with the results presented in earlier papers. For example, Lenssen (1968) reports that the make-up water demand Qm varies due to temperature in the range 2.4 to 3 1/KWh for an average coefficient of concentration K in the range 4 to 5. More detailed studies on the make-up water demand Qm were made by Ortner with regard to lignite fired power plants located in the Rhineland region (GFR).

Table 19

Make-up water demand

Power plant	Installed power /MW/	Years of observation	in m^3/ MWh		in m^3/ Gcal	
			average monthly	average annual	average monthly	average annual
1	15.8	1961-63	3.85-9.08	5.32-5.53	1.21-2.75	1.54-1.65
2	93.9	1960-62	3.00-6.10	3.95-4.15	1.30-2.59	1.68-1.76
3	156.4	1966-68	1.78-4.70	2.89-3.35	0.89-2.05	1.32-1.45
4	161.3	1961-62	3.12-5.19	3.97-4.09	1.30-2.16	1.65-1.70
5	179	1960-62	1.77-3.93	2.67-3.23	0.87-1.93	1.31-1.58
6	200	1963-78	1.89-4.80	2.42-3.23	1.15-2.60	1.39-1.91
7	220	1958-78	1.93-4.02	2.33-2.96	1.04-2.18	1.36-1.66
8	600	1967-68	1.15-4.05	2.09-2.73	0.84-3.39	1.56-2.30
9	840	1975-78	1.70-2.94	1.97-2.45	1.25-2.16	1.45-1.80
10	860	1975-78	2.39-3.35	2.76-3.05	1.78-2.41	1.99-2.26
11	1229.5	1973-78	2.02-3.28	2.55-2.76	1.32-2.58	1.59-1.97
12	1400	1966-68	1.77-3.35	2.37-2.56	1.27-2.59	1.84-2.00

Table 20

Monthly and annual average make-up water consumption indices in m^3/MWh over the periods under investigation

Power plant	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual average
1	4.02	4.74	4.51	5.31	5.65	6.29	6.77	6.87	6.86	5.46	4.48	4.54	5.44
2	3.18	3.83	3.97	4.70	5.14	4.86	4.85	4.17	3.70	3.68	3.36	3.09	4.04
3	3.02	3.21	2.62	2.95	3.08	3.08	3.14	3.83	3.33	3.60	3.74	2.50	3.13
4	3.42	3.44	3.68	4.46	3.82	4.38	4.87	4.16	4.62	3.83	3.81	2.85	4.03
5	2.62	3.17	2.78	3.15	3.27	3.14	3.01	2.84	3.02	2.56	2.95	2.62	2.93
6	2.51	2.67	2.81	2.87	3.24	3.36	3.04	3.04	2.93	3.13	2.60	2.55	2.88
7	2.34	2.46	2.56	2.65	2.87	3.07	3.08	3.00	2.81	2.71	2.48	2.34	2.67
8	2.59	2.86	2.89	2.70	2.74	3.23	3.46	2.81	2.71	2.48	2.21	2.57	2.77
9	2.03	2.02	2.17	2.23	2.30	2.41	2.36	2.33	2.37	2.32	2.07	1.90	2.17
10	2.80	2.86	2.88	2.84	2.99	2.88	2.92	2.94	2.85	3.02	2.92	3.00	2.90
11	2.37	2.40	2.54	2.67	2.85	2.91	3.05	3.05	2.80	2.52	2.48	2.35	2.66
12	2.19	2.19	2.05	2.35	2.67	2.87	2.78	2.57	2.49	2.46	2.22	2.16	2.41

Notice: for power plant No 11 the average covers the period 1973-78.

Table 21

Monthly and annual average make-up water consumption indices in m^3/Gcal over the periods under investigation

Power plant	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annu - al avera- ge
1	1.22	1.44	1.37	1.61	1.71	1.91	2.05	2.08	2.08	1.66	1.36	1.37	1.60
2	1.36	1.63	1.69	2.00	2.18	2.07	2.06	1.77	1.58	1.57	1.43	1.31	1.72
3	1.34	1.43	1.17	1.31	1.37	1.37	1.39	1.50	1.47	1.59	1.66	1.26	1.41
4	1.42	1.44	1.53	1.86	1.60	1.82	1.89	1.90	1.65	1.58	1.59	1.61	1.68
5	1.29	1.56	1.37	1.56	1.61	1.54	1.49	1.40	1.56	1.26	1.45	1.29	1.44
6	1.48	1.57	1.65	1.75	1.90	1.97	1.79	1.79	1.72	1.84	1.63	1.44	1.71
7	1.29	1.34	1.44	1.47	1.58	1.69	1.73	1.66	1.53	1.49	1.38	1.29	1.49
8	1.52	1.78	1.85	1.65	1.68	1.95	2.10	2.51	2.11	2.01	1.92	2.10	1.93
9	1.49	1.48	1.60	1.65	1.70	1.77	1.74	1.71	1.74	1.70	1.93	1.40	1.63
10	2.09	2.13	2.17	2.12	2.23	2.15	2.18	2.19	2.13	2.26	2.18	2.23	2.17
11	1.69	1.71	1.81	1.90	2.02	2.07	2.17	2.18	1.99	1.79	1.76	1.67	1.89
12	1.67	1.64	1.57	1.79	2.03	2.19	2.11	1.96	1.90	1.87	1.69	1.64	1.84

Notice: for power No 11 the average covers the period 1973-78.

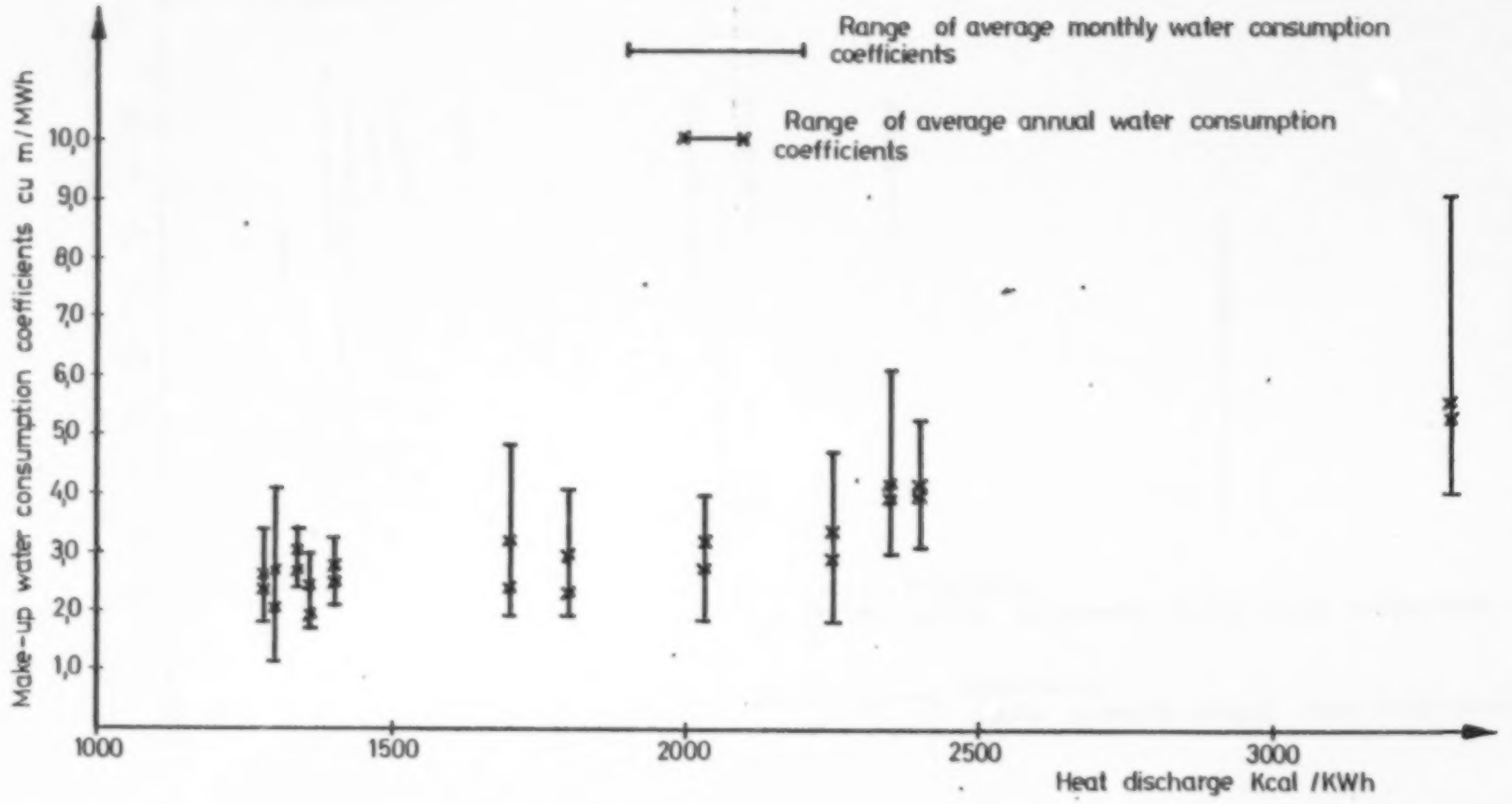

Fig. 18 Make-up water consumption coefficients in cu m/MWh and unit heat discharge in power plants under investigation

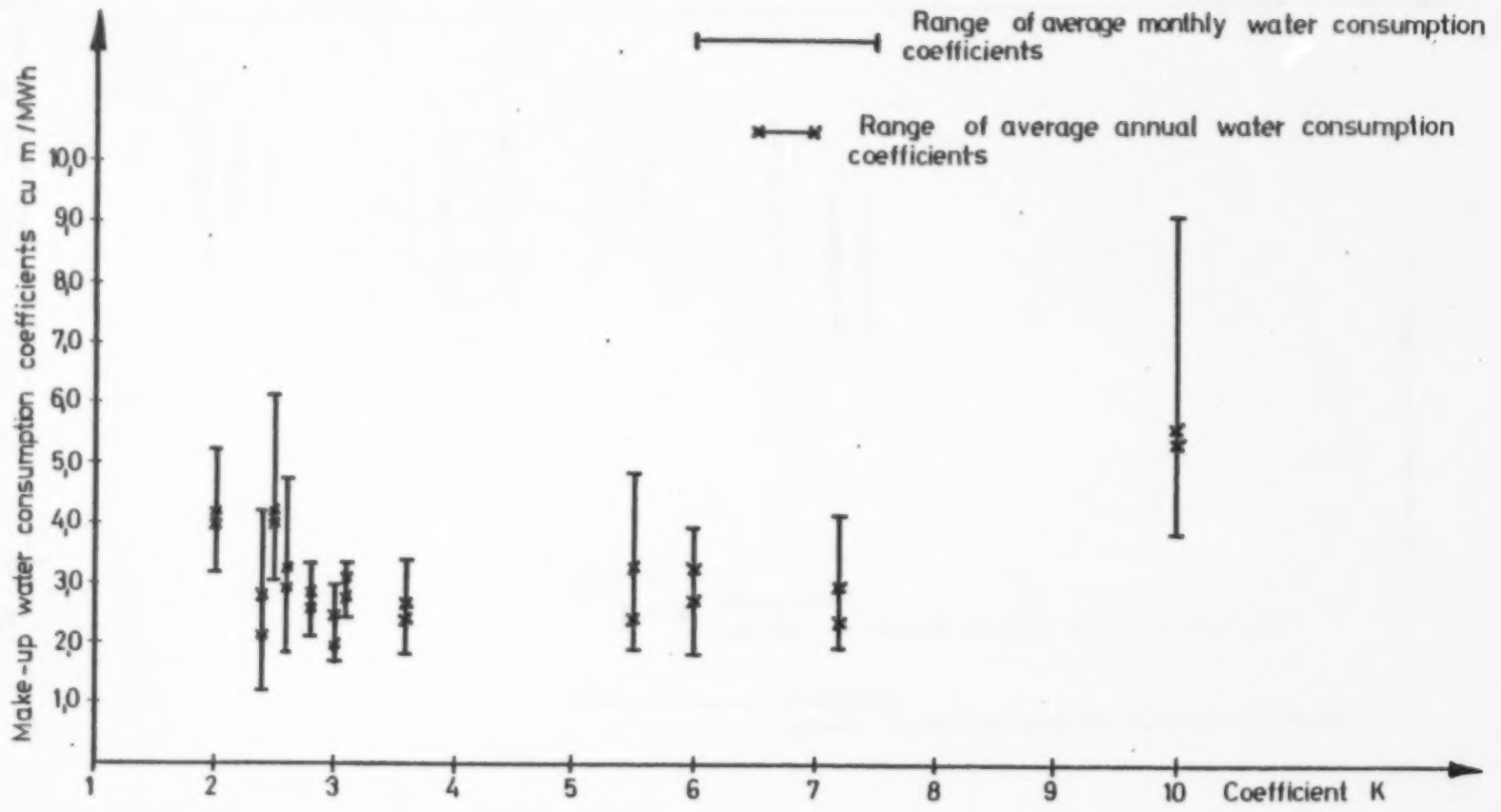

Fig. 17 Make-up water consumption coefficients in cu m/MWh and K coefficients in power plants under investigation

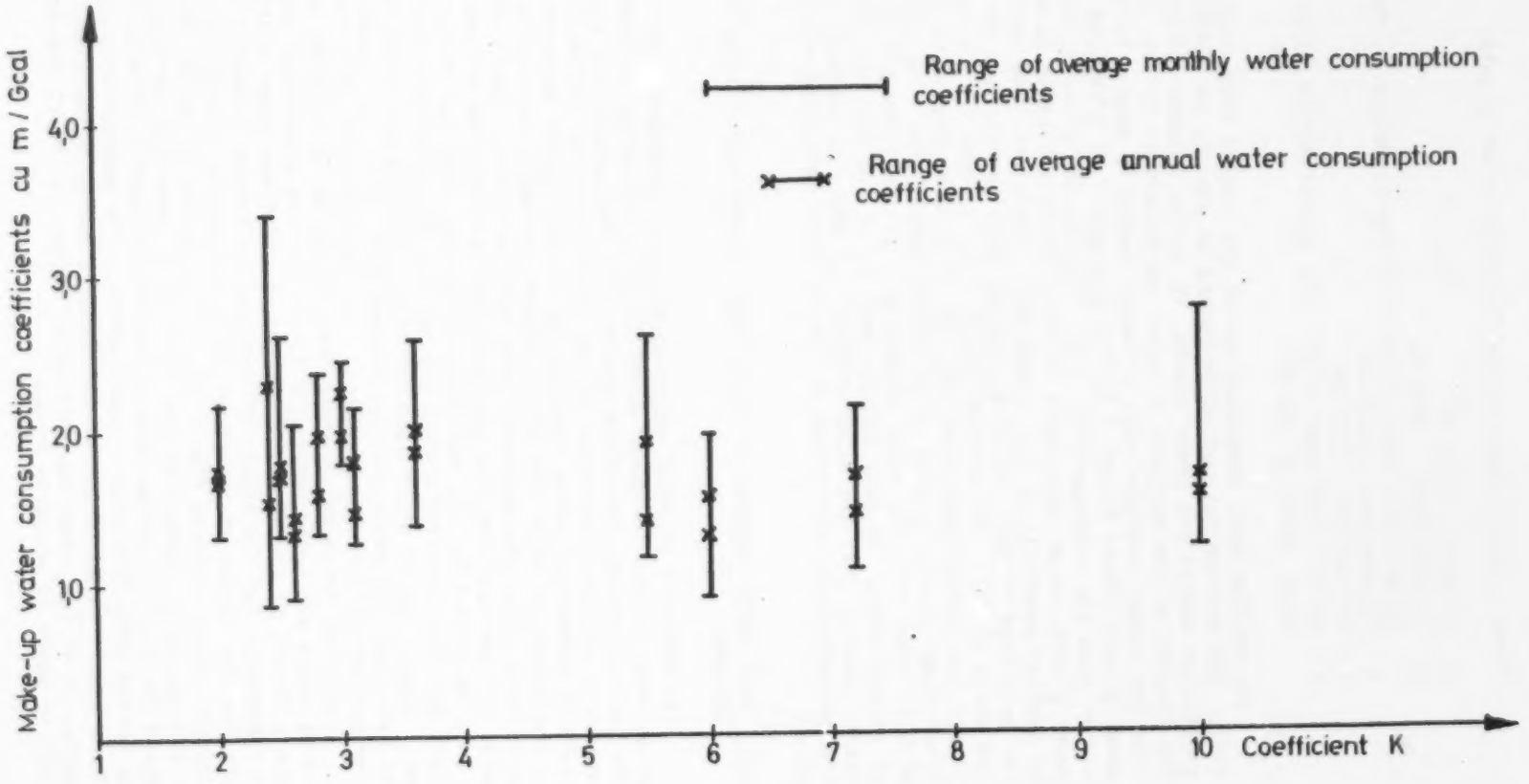

Fig 20 Make-up water consumption coefficients in cu m/Gcal and K coefficients in power plants under investigation

These studies involved the following power plants:

A - Fortuna - 1000 MW
B - Frimmersdorf - 2600 MW
C - An old type power plant with approximately 50 MW units
E - Niderausen - 2700 MW
F - Weisweiler - 2300 MW
G - an old type power plant with approximately 50 MW units of total power of 220 MW

The studies were conducted during the period from June 1966 to December 1968. The average make-up water demand Qm amounts to 2.435 1/kWh, but for particular months and power plants, it varies between 1.63 to 3.60 1/kWh. The results of the analysis of water management in Polish power plants show that the annual average index of water demand in modern Polish steam power power plants (Power Plants 5 to 12) averages 2.67 1/kWh and is about 10% higher than the corresponding index from the GFR (2.435 1/kWh). In Polish power plants, water management is more flexible because seasonal changes of indices generally do not exceed 20%. Therefore, the units m^3/Gcal for heat load to the cooling system are more appropriate for analysis than the units m^3/MWh. The average value of this index for Polish steam power plants (excluding Power Plant No. 10) is 1.68 m^3/Gcal with changes for other power plants ranging up to approximately 15%. The analysis of index m^3/Gcal shows that the water demand only slightly depends on the quality of intake water. In many cases, lower rates are obtained for more polluted water, showing that the water consumption does not strongly depend on the concentration coefficient K, but on other processes within the power plant.

3.5 Total Water Balance of Steam Power Plants with Closed Cycle Cooling Systems

The analysis of total water balance was developed based on data from 5 steam power plants for power plant capacity and water consumption, including the cooling system, the steam system, the heat generating system, hydro-transport and administrative use per month over the period of 1975-1978. Table 22 summarizes water consumption for particular purposes. Also shown is the source of water for ash transport, normally made-up by blowdown and waste water from the demineralizers and clarifiers. Small amounts of fresh water for ash sluicing are used only for certain time periods in power plants No. 6 and No. 11, but these quantities were not measured. Power plant No. 7 is provided with a dry ash and slag discharge system. The small quantities of water used for slag quenching are given in the Table. The municipal hot water heating systems are, as a rule, supplied with boiler blowdown and polluted condensates. For this purpose, only Power Plant No. 7 utilizes fresh water while Power Plant No. 6 utilizes only small quantities which are noted under the demand for the steamwater cycle. Approximately 85-95% of fresh water supplied to the steam power plant is utilized to compensate for the losses of the cooling system, almost 4 to 12% compensate for the losses of the power cycle and nearly 1 to 3% is utilized for administrative purposes (Table 22). Figures No. 21 to No. 24 show the course of average daily changes of the total water demand in particular months, demand for cooling system make-up and for production of electric energy over the period 1975-1978 under investigation. The maximum unit cooling water demand occurs in summer, when the electric energy production is normally lower. In winter, when the unit water demand is lower, the production of electric power is normally higher.

Table 22

Water consumption for particular purposes in power plants under investigations m^3/MWh

Steam power plant	Year	Cooling cycle		Steam -water cycle		Hot water heating systems	Ash transport	Slag quenching	Administrative purposes	Total fresh water demand
		fresh water	water treatment plant	fresh water	water preparation plant					
6	1975	3.12	n.d.	0.21	0.068	0.0260 [3]	n.d.	-	0.023	3.35
	1976	2.86	n.d.	0.19	0.048	0.0115	n.d.	-	0.021	3.07
	1977	2.88	n.d.	0.18	0.043	0.0309	n.d.	-	0,019	3,08
	1978	2.99	n.d.	0.21	0.047	0.0398	n.d.	-	0.022	3.22
7	1975	2.62	n.d.	0.36	0.013	0.0098 [4]	-	0.050	0.060	3.10
	1976	2.74	n.d.	0.32	0.012	0.0105	-	0.016	0.046	3.14
	1977	2.85	n.d.	0.28	0.013	0.0228	-	0.061	0.037	3.25
	1978	2.56	n.d.	0.30	0.014	0.0170	-	0.121	0.043	3.04
9	1975	2.45		0.19	0.040	0.024 [3]	0.050 [5]	-	0.050	2.69
	1976	2.16		0.19	0.040	0.021	0.074	-	0.065	2.42
	1977	2.10		0.15	0.030	0.020	0.021	-	0.072	2.32
	1978	1.97		0.18	0.040	0.019	0.023	-	0.074	2.22
10	1975	2.81	0.076	0.12	0.017		0.57 [5]	-	0.080	3.01
	1976	2.67	0.037	0.12	0.016		0.85	-	0.041	2.83
	1977	3.05	0.044	0.12	0.016		0.49	-	0.037	3.21
	1978	3.05	0.043	0.12	0.017		0.43	-	0.027	3.20
11	1975	2.55	0.098	0.16	0,032	0.0068 [3]	n.d.	-	0.025	2.74
	1976	2.55	0.098	0.17	0.023	0.0087	n.d.	-	0.020	2.74
	1977	2.71	0.104	0.17	0.029	0.0121	n.d.	-	0.021	2.90
	1978	2.68	0.104	0.17	0.021	0.0119	n.d.	-	0.022	2.87

Notice:
1. Within the range of 150 m^3/ month per power plant
2. Water in not processed
3. Polluted condensates boiler blowdowns
4. Fresh water
5. Cooling tower blowdown waste water from demineraliziers and clarifiers.

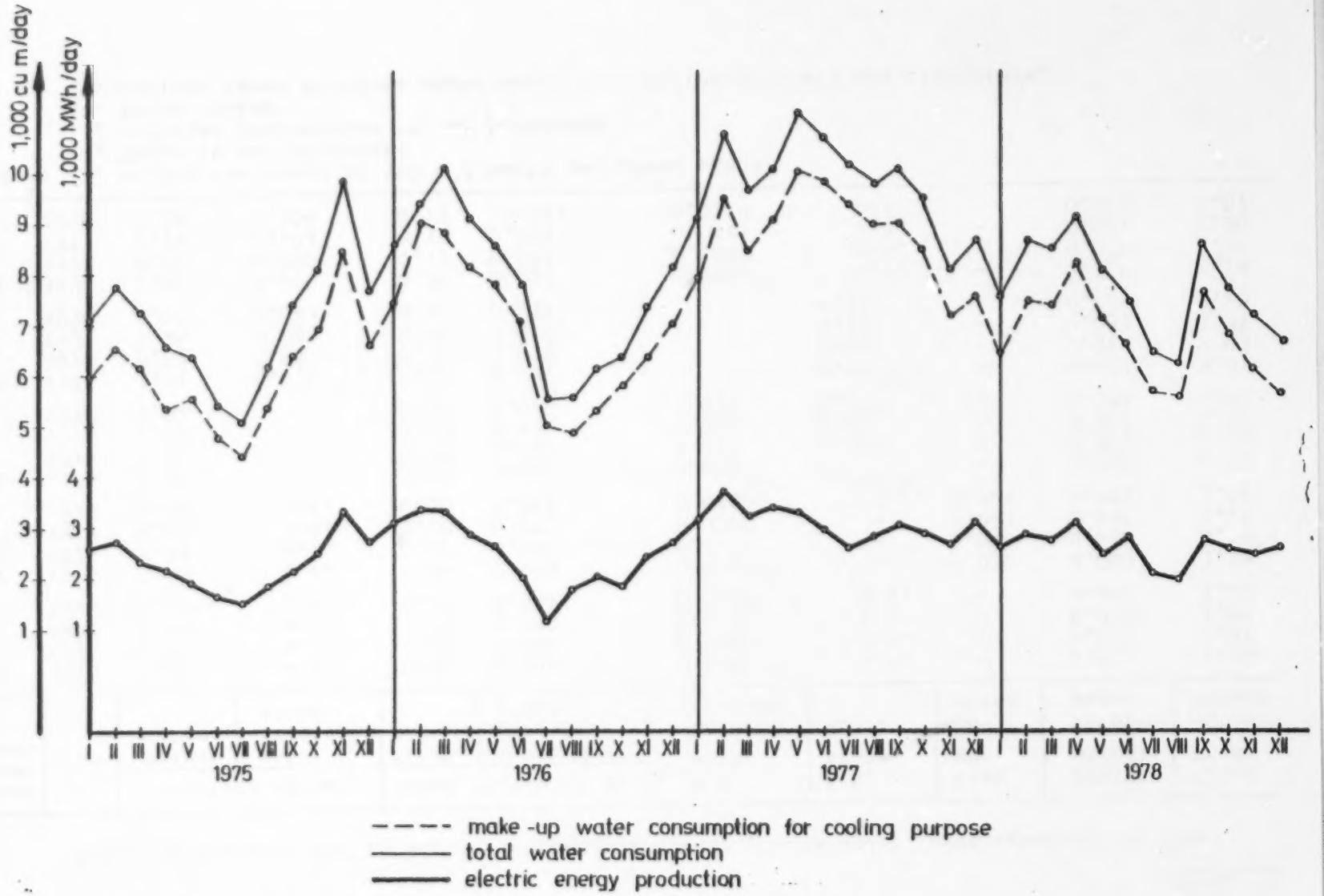

Fig. 21 Daily electric energy production and water consumption in power plant No 7

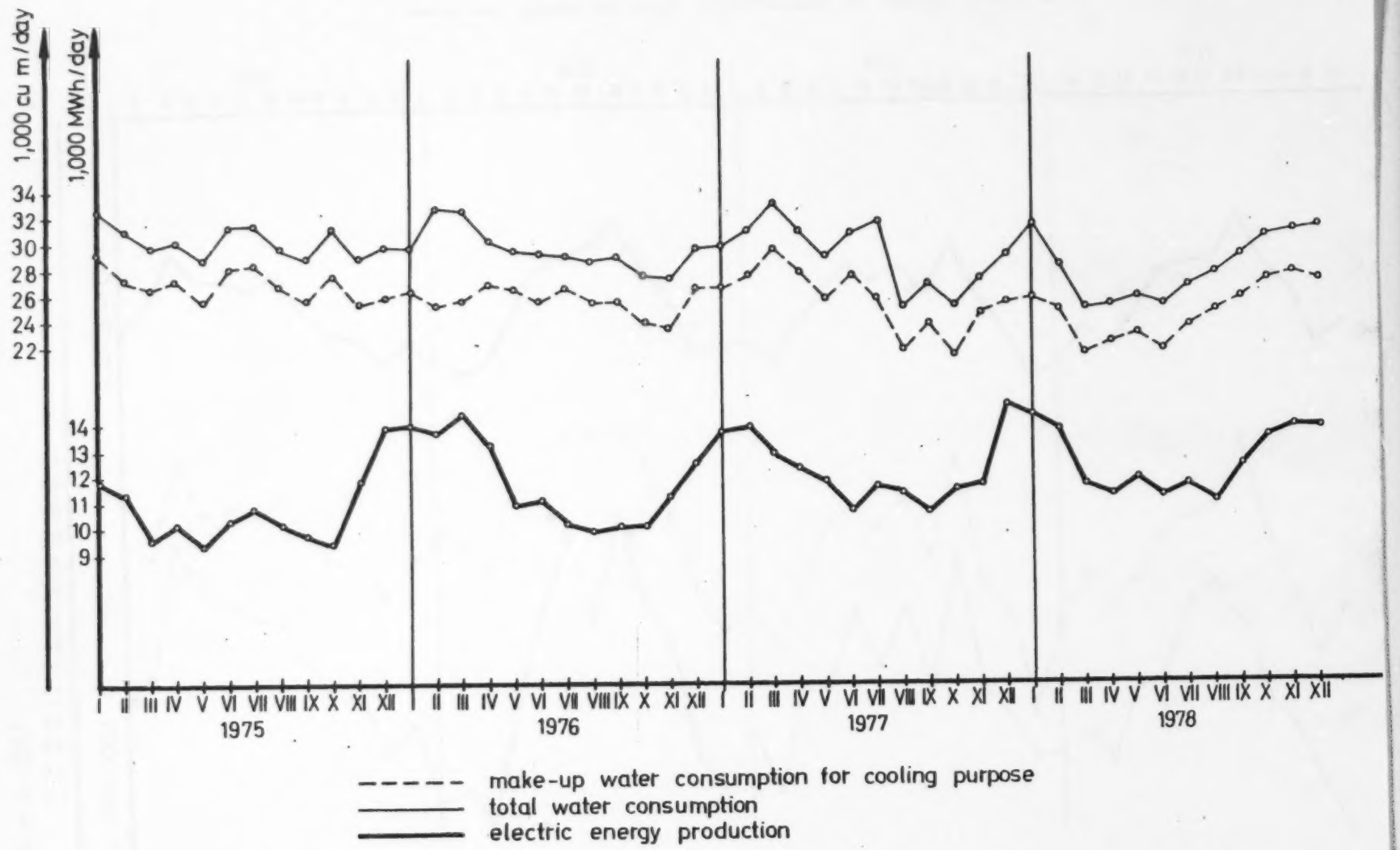

Fig. 22 Daily electric energy production and water consumption in power plant No 9.

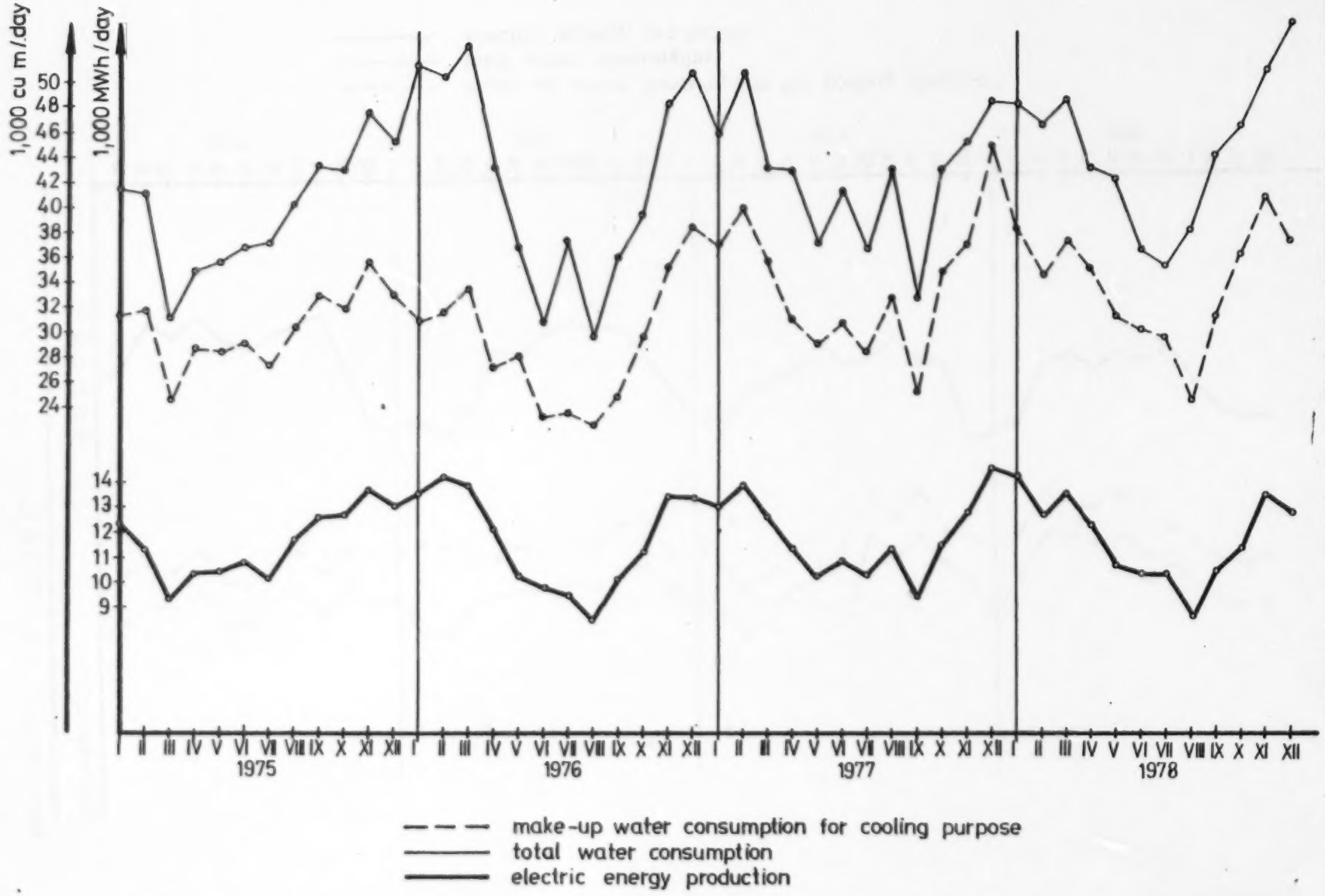

Fig. 23 Daily electric energy production and water consumption in power plant No 10

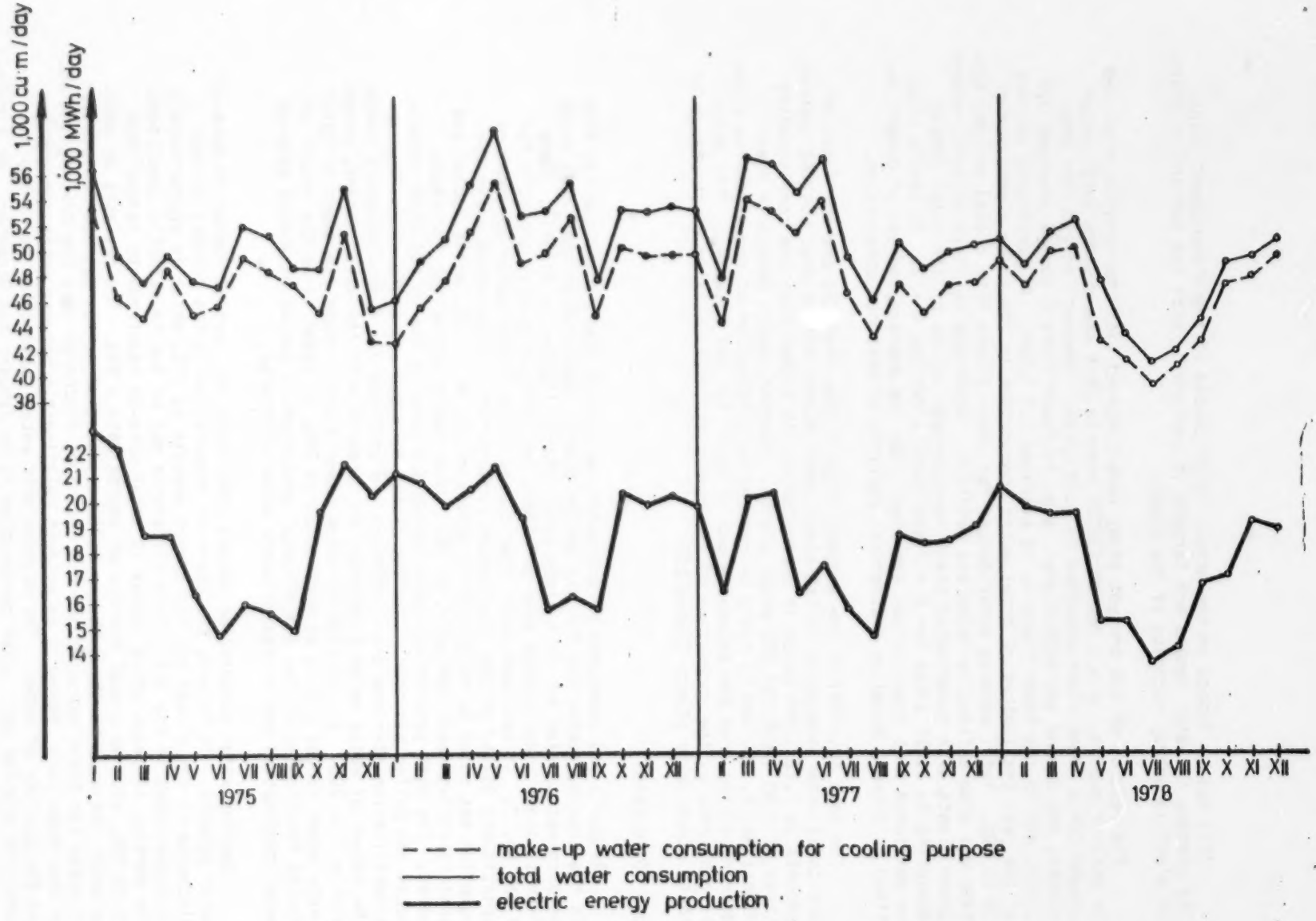

Fig. 24 Daily electric energy production and water consumption in power plant No 11

This has an impact on the annual water demand of the steam power plant. The changes in water demand are largely in conformity with the pattern of change of electric energy capacity of the plant.

The results of the present study were compared with the results presented in earlier papers. e.g., Ortner (1973) reports that the average total water demand for a power plant amounted to 2.80 1/kWh. However, in old type power plants, the demand was much higher, e.g. in Power Plant C demand averaged 3.8 1/kWh, and in the Power Plant G, it averaged 3.2 1/kWh. In particular seasons of the year the indices of total water consumption in the power plants varied 30 to 40%. Total make-up water demand for power plants with closed cooling systems was also defined by Heine and Weidlich. According to these authors, modern power plants with superheated steam have average values of the total demand amounting to 3.017 1/kWh for K = 2 and 2.267 1/kWh for K = 3. It should also be mentioned that these values are lower than the average indices of demand defined by Ortner, based on statistical analysis of measured consumption.

The data obtained in the present project show that the average index of the total water demand in Polish steam power plants with closed cooling systems amounts to 2.92 1/kWh which is approximately 4% higher than the corresponding index of 2.80 1/kWh for GFR power plants. However, water demand in Power Plants No. 6, 10, and 11 could be reduced by elimination of the excessive blowdown resulting from the excessive use of water for ash disposal. This point is confirmed by the proportion of the amount of total waste water discharge in these steam power plants (Table 23).

3.6 Discussion

Research was conducted on the water balance of steam power plants, both in the cooling system and for the entire plant. Research on the total water balance was carried out in 5 steam power plants located in Silesia. Data from 12 other power plants were utilized, including a special analysis for Plant No. 7. It has been noted that closed cycle system water consumption constitutes 85-95% of the total water consumption. Water-steam cycle consumption was noted to range within approximately 4 to 12%, while social and administrative needs consume 1 to 3%. Other needs are mainly for waste water. The heat generating cycle losses are usually due to polluted condensates and boiler blowdown. Cooling system blowdown and waste water from demineralization stations and clarifiers are utilized for hydro-transport needs. The amount of waste water discharge, as compared with the water demand, ranges within 5 to 30%. In the case of steam power plants, where the share of total waste water ranges within as much as 20 to 30%, it seems to be the result of faulty functioning of the ash disposal system which causes excessive make-up water consumption and increased waste water discharge.

Cooling water evaporation losses constitute the largest factor in make-up water balance. In Poland, the share of evaporation in the process of heat discharge in the closed cooling towers amounts to 77%, which is approximately 3% higher than in the GFR. This difference may be due to climatic conditions. The portion of evaporation losses in total make-up requirements ranged from 75 to 90%, with an annual average of approximately 85%. The analysis of make-up water consumption shows that a definite relation exists between consumption of water for these purposes and the unit heat discharge into the cooling system. On the other hand, there is no evident relationship between water consumption and the quality of water. The maximum unit water consumption is in May and June; the minimum unit water consumption is in January and December. As a rule, deviations from the annual average do not exceed 20% - depending on the season

Table 23

Share of fresh water consumption for particular purposes in power plants under investigation /%/

Steam power plant	Year	Cooling cycle	Water steam cycle	Hot water heating system	Ash transport and slag guenching	Administrative purposes	Total waste water
6	1975	93.1	6.2	0.8	n.d.	0.7	24.8
	1976	93.2	6.1	0.4	n.d.	0.7	20.7
	1977	93.5	5.9	1.0	n.d.	0.6	22.1
	1978	92.9	6.4	1.2	n.d.	0.7	9.2
7	1975	84.5	11.7	0.3	1.6	1.9	7.3
	1976	87.3	10.3	0.3	0.5	1.5	4.9
	1977	87.7	8.6	0.7	1.9	1.1	5.8
	1978	84.2	9.9	0.6	3.9	1.4	7.5
9	1975	91.1	7.0	0.9	1.8	1.9	12.2
	1976	89.4	7.9	0.9	3.0	2.7	11.8
	1977	90.4	6.5	0.9	0.9	3.1	8.4
	1978	88.6	8.1	0.8	1.0	3.3	9.6
10	1975	93.4	4.0	n.d.	18.9	2.6	22.9
	1976	94.3	4.2	n.d.	30.0	1.7	34.7
	1977	95.0	3.7	n.d.	15.3	1.2	30.6
	1978	95.3	3.8	n.d.	13.4	0.9	31.9
11	1975	93.1	5.9	0.02	n.d.	1.0	25.4
	1976	93.1	6.2	0.03	n.d.	0.7	17.8
	1977	93.4	5.9	0.04	n.d.	0.7	15.2
	1978	93.3	5.9	0.04	n.d.	0.8	18.3

treatment of the make-up water. One of the reasons for higher water consumption could be faulty sewage management, mainly as a result of inefficient ash-removal systems. A significant decrease of water demand by the power plant can be obtained by reusing water for the cooling system and by use of sedimentary waters from ash disposal and municipal sewage. Such solutions also limit or even eliminate troublesome discharges resulting from ash system disposal. Experience gained in Poland shows that these approaches may allow reduction of the total water supply requirement by approximately 15 to 20% with considerable reduction of the amount and load of discharged pollutants (Gadkowski, et al. 1980). Because of large variations in the amount of heat discharged to the cooling systems, it is suggested that indices of water demand in l/Mcal or M^3/Gcal of discharged heat should be used when comparisons of power plant water need are made.

Appendix A

Specification of steam power plants

Power plant	Year	Rated output MW	Running time per year T hour	Heat discharge to the cooling system Kcal/kWh	Cooling water		
					make-up water source	make-up water preparation method	concentrating degree K
1	2	3	4	5	6	7	8
1	1961 1962 1963	15.8	1200	3300	water from deep well	water decarbonized, with lime corrected by sodium metahexaphos - phate to 2 mg P_2O_5 /l level	10
2	1960 1961 1962	93.6	4100	2350	bituminous coal mine water and waste water from chemical plant	water decarbonized with lime	2.5
3	1966 1967 1968	156.4	4700 4700 4640	2290 2190 2270	bituminous coal mine water	decarbonized with lime	2.5
4	1961 1962	161.3	3700	2400	highly polluted river	hydrochloride acid grafting to general hardness 1-1.5 mval/l	2.0
5	1960 1961	179	5200	2030	bituminous coal mine water /10%/ waste water from chemical plant /20%/, municipal water /70% /	hydrochloride acid grafted water	6.0

1	2	3	4	5	6	7	8
6	1963	200	6200	1740	municipal water	hydrochloric acid grafting and stabilization with silenal S	4 - 7
	1964		6000	1740			
	1965		6200	1711			
	1866		6550	1690			
	1967		6950	1650			
	1968		6600	1680			
	1975		5800	1715			
	1976		6100	1715			
	1977		60000	1715			
	1978		5500	1715			
7	1958	220	5900	1770	municipal water	decarbonization with lime and filtration	7.2
	1959		5300	1770			
	1960		4700	1770			
	1961		6600	1770			
	1962		6500	1770			
	1963		6700	1770			
	1964		5900	1770			
	1965		6000	1770			
	1966		5600	1770			
	1967		5800	1850			
	1968		5500	1800			
	1975		3900	1840			
	1976		4100	1840			
	1977		5200	1840			
	1978		4400	1840			
8	1965	160	5200	1370	water from highly polluted river	water prepared on cation exchangers	2.4
	1966	360	5800	1310			
	1967	540	4600	1235			
	1968	600	3800	1360			
9	1975	840	4800	1360	river water	decarbonization with lime and coagulation with ferric sulphate	
	1976		5100	1360			
	1977		5300	1360			
	1978		5500	1360			

1	2	3	4	5	6	7	8
10	1975 1976 1977 1978	860	4900 5000 5000 5000	1340 1340 1340 1340	water from river, municipal mains and mine water	sulphuric acid grafting	3
11	1958 1959 1960 1961 1962 1963 1964 1965 1966 1973 1974 1975 1976 1977 1978	199.1 199.1 199.1 187.5 175.0 175.0 175.0 175.0 175.0 1229.5 1229.5 1229.5 1229.5 1229.5 1229.5	5860 5690 5870 5800 6100 5900 5800 5100 4920 5500 5500 5500 5700 5300 5100	2310 2310 2310 2310 2310 2310 2310 2310 1957 1423 1445 1407 1400 1400 1400	bituminous coal mine water	till 1960 decarbonization with lime and hydrochloride acid grafting from 1960 decarbonization with lime and coagulation with ferric sulphate and stabilization with sodium polyphosphate	till 1960 K = 4 after 1960 K = 2.5-3.0
12	1964 1965 1966 1967 1968	905.8 1283.3 1400.0 1400.0 1400.0	5900 5200 5150 5600 5700	1360 1330 1310 1290 1280	river water	without preparation	3.6

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